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(71) Applicant: BIO-TECHNOLOGY GENERAL CORP. [US/US]; 1250 Broadway, New York, NY 10001 (US).			
(72) Inventors: VOGEL, Tikva ; 4 Kosover Street, 76 408 Rehovot (IL). PANET, Amos ; 11 Harav Schrim Street, 96 920 Jerusalem (IL).			
(74) Agent: WHITE, John, P.; Cooper & Dunham, 30 Rockefeller Plaza, New York, NY 10112 (US).			
(54) Title: METHOD OF INHIBITING CELL PROLIFERATION USING APOLIPOPROTEIN E			
(57) Abstract <p>The present invention provides a use of ApoE for inhibition of proliferation of actively proliferating cells including tumor cells. This method comprises contacting the cells with an amount of Apolipoprotein E (ApoE) effective to inhibit cell proliferation.</p>			

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<b>(54) Title:</b> METHOD OF INHIBITING CELL PROLIFERATION USING APOLIPOPROTEIN E  <b>(57) Abstract</b>  The present invention provides a use of ApoE for inhibition of proliferation of actively proliferating cells including tumor cells. This method comprises contacting the cells with an amount of Apolipoprotein E (ApoE) effective to inhibit cell proliferation.		

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METHOD OF INHIBITING CELL PROLIFERATION  
USING APOLIPOPROTEIN E

5

Background of the Invention

10 This invention relates to the use of Apolipoprotein E in a method of inhibiting cell proliferation.

15 Throughout this specification, various publications are referenced within parentheses. Full citations for these references may be found at the end of the specification immediately preceding the claims. The disclosures of these publications in their entireties are hereby incorporated by reference into this application in order to more fully describe the state of the art as known to those skilled therein as of the date of the invention disclosed and  
20 claimed herein.

In normal tissue, cell growth and DNA synthesis are closely controlled by a variety of regulatory factors operating on both positive and negative levels (Weinberg et al., 1989).  
25 As a normal cell develops into a solid tumor, it undergoes several changes (Folkman, 1989; Liotta, 1992). At the physiologic level, growth is stimulated, immunity is decreased, and new blood vessel formation is induced. This capacity to induce new blood vessels, i.e., angiogenesis and neovascularization, is characteristic of most malignant  
30 cells and is a prerequisite of solid tumor growth (D'Amore, 1988; Folkman, 1976). Moreover, new blood vessels penetrating the tumor are frequent sites for tumor cell entry into the circulation. Angiogenesis is also necessary  
35 for expansion of a metastatic colony (Aznavorian, 1991). In addition to malignant cell growth, other diseases are

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also characterized by abnormal neovascularization, including neovascular glaucoma, diabetic retinopathy, and rheumatoid arthritis (Folkman, et al., 1989).

5 Malignant cells produce many factors that stimulate  
endothelial cell proliferation and migration and allow new  
capillary beds to form within the tumor nodule (D'Amore,  
1988; Shing, et al., 1985). A variety of agents have been  
10 suggested as potential modulators of cell proliferation,  
including heparin and heparin sulfate (Castellot, et al.,  
1987; Clowes, 1977), and growth factors and their inhibitors  
(Edelman, et al., 1992; Liu, 1990; Schweigerer, et al.,  
1987). Most of these factors also appear to be natural  
15 components of normal tissue. To date, the most studied  
growth factor has been basic fibroblast growth factor  
(bFGF), a member of the fibroblast growth factor family  
(Basilico and Moscatelli, 1992; Schweigerer, et al., 1987;  
Thomas and Gimenez-Gallego, 1986). bFGF is a strong  
20 heparin-binding molecule, present in virtually all tissues  
and having multiple mitogenic and angiogenic effects (Thomas  
and Gimenez-Gallego, 1986). In vascular endothelial cells,  
bFGF stimulates a number of functions involved in the  
formation of blood vessels and angiogenesis. bFGF is  
25 considered to be one of the most potent angiogenesis  
inducers both in vivo and in vitro (Folkman, 1976; Folkman  
and Klagsbrun, 1987). Recently it was shown that  
intravenous infusion of bFGF stimulated endothelial  
regeneration and SMC proliferation (Edelman, et al., 1992;  
Lindner and Reidy, 1991; Lindner, et al., 1990) after  
30 balloon-induced endothelial denudation. In these studies,  
it was confirmed that bFGF was both angiogenic and mitogenic  
for SMC in vivo and also demonstrated that these two effects  
are coupled. bFGF also binds to heparan sulfate  
35 proteoglycans (HSPG) of both the extracellular matrix (ECM)  
and basement membrane (Folkman, et al., 1988; Vlodavsky, et

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al., 1987). Thus, it has been postulated that bFGF may play an important role in the pathogenesis of atherosclerotic vascular disease.

5     The role of HSPG in regulating cell growth and  
differentiation has been described (Burgess and Maciag,  
1989; Klagsbrun and Baird, 1991; Ruoslahti and Yamaguchi,  
1991). Many proteoglycans are constituents of the ECM or  
10     function as a low-affinity cell surface receptor for the  
interaction of growth factors, including bFGF and other  
heparin-binding growth factor molecules. The role of HSPG  
as binders of bFGF appears to protect bFGF from degradation,  
and is important in providing a matrix or cell surface bound  
reservoir of bFGF. Yayon, et al. (1991) have shown that  
15     bFGF binding to its high-affinity receptor requires prior  
binding either to the heparan sulfate side chains of a  
membrane HSPG or to free heparan sulfate (heparin) chains,  
and speculate that glycosaminoglycans may change the  
conformation of bFGF so that it acquires the ability to bind  
20     to its receptor. Binding of growth factors to proteoglycans  
have also been observed with several other growth factors  
that bind to heparin or heparan sulfate (Ruoslahti and  
Yamaguchi, 1991). Because proteoglycans are abundant and  
ubiquitous tissue components, they are likely to attract  
25     most of these growth factors and cytokines that have  
affinity for the glycosaminoglycan. It may be that growth  
factors and cytokines were meant to act on their target  
cells only over a short range, and that their immobilization  
at the cell surface and in ECM (through proteoglycan  
30     binding) accomplishes that goal (Ruoslahti and Yamaguchi,  
1991).

Apolipoprotein E (ApoE) is a plasma protein having strong  
affinity for heparin and HSPG (Cardin, et al., 1988; Mahley,  
35     1988; Mahley, et al., 1979; Weisgraber, et al., 1986). ApoE

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participates in plasma lipoprotein metabolism through its high-affinity interaction with cell surface receptors including the low-density lipoprotein (LDL) and the more recently identified apoE receptor, LDL receptor-related protein (LRP) (Hertz, et al., 1988; Lund, et al., 1989; Yamada, et al., 1989; 1992). The domain of apoE responsible for binding to the LDL receptor has been identified (Dyer and Curtiss, 1991; Wilson, 1991). This domain is a 20-amino acid region comprised of residues 140-160 of the apoE molecule. It has long been known that binding of ApoE to the LDL receptor depended on its association with lipids (Innerarity, 1979). However, from results with synthetic peptides binding to the LDL receptor in vitro, one can assume there is direct binding of the peptide to the LDL receptor, or one could speculate that the LDL receptor is not the only binding site on the cell.

It has been shown that intravenous administration of ApoE into hyperlipidemic rabbits resulted in reduced plasma cholesterol levels (Mahley, et al., 1979; Yamada, et al., 1989). Recently (Yamada, et al., 1992), following a sustained intravenous administration of ApoE into Watanabe heritable hyperlipidemic rabbits, progression of atherosclerosis was significantly prevented. Administration of exogenous ApoE had affected both the number and size of atherosclerotic lesions in the aorta. However, in these experiments there was no significant difference in plasma cholesterol levels between ApoE-treated and nontreated control animals. Based on these and other experiments, the effect of ApoE on atherogenesis might neither be solely nor directly related to plasma cholesterol levels.

ApoE is ubiquitously synthesized in many tissues including liver, intestine, adrenal gland, kidney, lung, spleen, testes, ovary, and brain (Mahley, 1988). Recently, it has

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been found in both inflamed and non-inflamed synovial fluid (Terkeltaub, et al., 1991). ApoE can function in tissue repair by modulating lipid redistribution locally (Hui, et al., 1980; Mahley, 1988). However, it has also been  
5 observed that apoE is synthesized and secreted by a number of cells that do not necessarily participate in cholesterol homeostasis (Boyles, et al. 1989; Hui, et al., 1980).

In addition to its effect on lipoprotein metabolism, apoE  
10 also possesses a variety of functions that are unrelated to lipid transport (Mahley, 1988). A potent suppression of lymphocyte activation by mitogens and antigens by ApoE-bearing lipoproteins and ApoE polypeptides has been observed (Cardin, et al. 1988; Hui, et al., 1980). The present  
15 invention discloses the effect of ApoE on proliferation and migration of several cell types.

Summary of the Invention

A method of inhibiting actively proliferating cells is disclosed. This method comprises contacting the cells with  
5 Apolipoprotein E (ApoE) in an amount effective to inhibit cell proliferation.

A composition is provided comprising Apolipoprotein E in an amount effective to inhibit cell proliferation.  
10

The invention additionally provides a method of treating a subject suffering from excessive cell proliferation which comprises contacting the excessively proliferating cells with an effective amount of Apolipoprotein E so as to  
15 inhibit the excessive cell proliferation.

Further, the present invention provides a method of treating a subject afflicted with a tumor which comprises contacting the tumor with an effective amount of an Apolipoprotein E in  
20 conjunction with a chemotherapeutic agent so as to inhibit proliferation of the tumor cells.

Additionally, the present invention provides a method of treating a subject afflicted with a tumor which comprises  
25 contacting the tumor with an effective amount of Apolipoprotein E in conjunction with an amount of irradiation so as to inhibit proliferation of the tumor cells.

30 Additionally, the invention provides a method of treating a subject suffering from a disorder involving increased neovascularization. This method comprises administering to the subject an amount of Apolipoprotein E effective to normalize neovascularization.

Brief Description of the Figures

Figure 1: The effect of heparin binding molecules on the incorporation of [<sup>3</sup>H]thymidine into bovine aortic endothelial cell (BAEC) DNA was tested as described in Examples 1 and 2 using protocol M2, either in the presence of fetal calf serum (FCS) (1% and 2.5%) alone [control (ctr)], or with added basic fibroblast growth factor (bFGF). (All other samples were tested using 10 ng/ml). When indicated, 0.05 or 0.5  $\mu$ M of met-apolipoprotein E (+E.05 or +E0.5, respectively) or recombinant thrombospondin (rTSP) 18 Kd (+T.05 or +T.5) were added to the wells containing FCS and bFGF. The mitogenesis assay was terminated after 42 hr.

Figure 2: The time course of the incorporation of [<sup>3</sup>H]thymidine into BAEC DNA was obtained. DNA synthesis was tested on a newly-attached cell culture according to mitogenesis protocol M2 (see Example 1-Methods). Cells were plated in Dulbecco's modified Eagles's medium (DMEM)-containing bFGF (10 ng/ml) and 1% FCS alone (ctr) or together with 0.5  $\mu$ M of the indicated molecules [(rTSP) 18 Kd, recombinant fibronectin (rFN) 33Kd, or met-apoE].

Figure 3: Incorporation of [<sup>3</sup>H]thymidine into pre-attached BAEC culture was tested according to protocol M1, at either 0.5% FCS alone or together with bFGF (10 ng/ml). Met-apoE at the indicated concentrations was added to the cells 5 days after plating, and [<sup>3</sup>H]thymidine incorporation was tested the next day after pulsing the cells for 5 hr and as indicated in protocol M1.

Figure 4: Incorporation of [<sup>3</sup>H]thymidine into a pre-attached, dense culture of BAEC was studied in a preattached culture. Mitogenesis was tested according to protocol M1, using 0% or 0.5% FCS (0 and .5, respectively), together with

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bFGF, 10 ng/ml (0F and .5F, respectively), or in combination with 0.5  $\mu$ M met-apoE (0FE and .5FE, respectively). The mitogenesis assay was terminated after 40 hr.

5      **Figure 5:**      Incorporation of [ $^3$ H]thymidine into BAEC culture was tested in the presence of bFGF (10 ng/ml) and one of two concentrations of FCS (as indicated in the figure) either alone (control), or together with met-apoE (0.5  $\mu$ M), added to the newly plated culture at time zero  
10      (designated as 0-40), or at 15 hr or 22 hr after plating (designated as 15-40 and 22-40, respectively). [ $^3$ H]thymidine was also added at time zero to all wells as indicated in protocol M2, and the assay was terminated after  
15      40 hr. Incorporation is expressed as a percent of control labelled with [ $^3$ H]thymidine for the same time in the absence of ApoE.

20      **Figure 6:**      The effect of bFGF on inhibition by ApoE was studied. The proliferation assay was performed with culture of BAEC-1, as indicated in protocol P1, in the presence of  
25      5% FCS either alone (ctr) or together with 20 ng/ml of bFGF. Where indicated, various concentrations of met-apoE were added 1 day after cell plating. The cell number was monitored as indicated in protocol P1.

30      **Figure 7:**      Incorporation of [ $^3$ H]thymidine into bovine corneal endothelial cell (CBEC) culture was studied using various concentrations of FCS (ctr) as indicated (0%, 1%, or 2%). To this, growth factors were added either alone (bFGF [10 ng/ml] or EGF [50 ng/ml]), or together with met-apoE (E, 0.5  $\mu$ M) or FN 33 Kd (FN, 0.5  $\mu$ M). The mitogenesis assay was performed as described in protocol M2, and terminated after  
44 hr.

Figure 8: The proliferation assay was performed with a culture of CBEC as indicated in protocol P2, in the presence of FCS and bFGF alone (control) at 5% and 10 ng/ml, respectively. When indicated, various concentrations of either met-apoE or FN 33 (rFN 33 Kd) were added to the cells at time zero. The average absorbancy of triplicate samples was calculated and expressed as percent of control.

Figure 9: The reversibility of ApoE inhibition was studied. CBEC culture in 1% FCS and 10 ng/ml bFGF was tested for [<sup>3</sup>H]thymidine incorporation after 40 hr of labeling using protocol M2 (control). To parallel cultures, met-apoE was added at time zero at the indicated concentrations and either left for the entire labeling period (0-40) or for only 22 hr (0-22). For all tested cultures, media was replaced after 22 hours with the appropriate combination, including the starting concentrations of FCS, bFGF, and [<sup>3</sup>H]thymidine.

Figure 10: Incorporation of [<sup>3</sup>H]thymidine into culture of A2058 human melanoma cells was tested as described in protocol M2, and in the presence of 0.5% FCS and bFGF (10 ng/ml) either alone (ctr) or together with 0.5  $\mu$ M and 1.5  $\mu$ M met-apoE (0.5E and 1.5E, respectively), 0.5  $\mu$ M TSP 18 Kd (0.5T18), 0.5  $\mu$ M TSP 28 Kd (0.5T28), or 0.5  $\mu$ M FN 33 Kd (0.5FN33). The assay was terminated after 32 hr.

Figure 11: Incorporation of [<sup>3</sup>H]thymidine into a culture of human mammary tumor (MDA-435) cells was carried out according to protocol M2, and in the presence of 0.5% FCS and bFGF (10 ng/ml) alone (ctr) or with the addition of 0.5  $\mu$ M met-apoE (E) or TSP 18Kd or with 75  $\mu$ g/ml heparin (Hep). The assay was terminated after 42 hr.

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**Figure 12:** Proliferation of smooth muscle cells (SMC) was performed as indicated in protocol P1, in the presence of either 0.5% or 5% FCS alone (ctr), or combined with bFGF (+F, 20 ng/ml). Where indicated, met-apoE (E) (4  $\mu$ M) was added to the culture at time zero.

**Figure 13:** The incorporation of  $^{35}$ S-methionine was examined as published (D. Blake 1990) with a slight modification. Briefly, CBEC cells were plated into 6-well tissue culture dishes in DMEM + 10% FCS at  $10^5$  cells/well. After 24 hr, cells were washed 3 times with PBS and the media was changed to DMEM minus methionine (for methionine depletion) either alone (ctr) or together with met-apoE (0.5  $\mu$ M). After 1 hr, 0.25  $\mu$ Ci [ $^{35}$ S]methionine (1268 Ci/mmol, Amersham) was added, and the culture was incubated at 37°C/5% CO<sub>2</sub> for 6 hr. Cells were washed twice with phosphate buffered saline (PBS) containing 10 mM EDTA and 1 mM phenyl-methyl-sulfonyl and then suspended in the same buffer. The cells were lysed with 20 mM ammonium hydroxide (NH<sub>4</sub>OH), then aliquots of the cell lysate were precipitated with 5 volumes of 20% trichloroacetic acid (TCA). After 10 minutes in ice the TCA solution was filtered on glass microfiber filters (GF/C, Whatman), then the filters were washed 3 times with 5% cold TCA and 1 time with 70% ethanol. The radioactivity of the TCA-insoluble [ $^{35}$ S]methionine-labeled protein was monitored by  $\beta$  counts.

**Figure 14:** Chemotaxis of BAEC to bFGF was carried out in a modified Boyden chamber as previously described (Taraboletti, 1990) using 5  $\mu$ m pore size polycarbonate PVP-free nucleopore filters. Semiconfluent cells were trypsinized, washed with 10% FCS, allowed to equilibrate in 10% FCS-DMEM for 2 hours at room temperature while shaking, and then pelleted, and resuspended in medium containing 0.1% BSA. Cells were used immediately at a concentration of

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10<sup>6</sup>/ml and checked for migration either alone or together with the indicated concentration of met-apoE (E) toward a gradient of 0.1% BSA alone (ctr) or together with bFGF (33 ng/ml). Migrated cells in triplicate samples were monitored after 4.5 hr of incubation at 37°C, and are expressed as a percent of the migration toward 0.1% BSA (ctr).

Figure 15: This figure shows plasmid pTVR 590-4 which was deposited in E. coli W1485 under ATCC Accession No. 67360. Plasmid pTVR 590-4 is a good expressor of met-apoE under control of the  $\lambda$ P<sub>1</sub> promoter as is described in Example 1. (E. coli W1485 is freely available from ATCC under Accession No. 12435.)

Figure 16: The construction of plasmid pE2-5 encoding ApoE containing amino acids 1-217 is described. Plasmid pTV 194-80 (disclosed in coassigned U.S. Patent No. 5,126,252, Figure 22) was digested with restriction enzymes BssHII and BglII. The large fragment was isolated and ligated to the synthetic linkers shown in the Figure. The resulting plasmid was designated pE2-5.

Figure 17: The construction of plasmid pTVR6-2 expressing ApoE having amino acids 1-217 is described. A 1200bp fragment containing the  $\lambda$  CI gene under control of a portion of the deoP1 promoter sequence was isolated from ClaI digestion of plasmid pFSAL-B27 (ATCC Accession No. 67071; also disclosed in European Patent Application Publication No. 303,972). The 1200bp fragment was then ligated to ClaI digested plasmid pE2-5 (Figure 16). The resulting plasmid, designated pTVR6-2, contains both the ApoE structural gene and the  $\lambda$  CI repressor gene, and is therefore an independent plasmid, not limited to use in a host containing the  $\lambda$  CI repressor but able to express the ApoE polypeptide fragment in a wide variety of hosts. It is

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not presently known whether an additional N-terminal methionine is present. Plasmid pTVR6-2 was deposited in E. coli 4300 with the American Type Culture Collection, 12301 Parklawn Drive, Rockville, Maryland on July 26, 1993 under  
5 Accession No. 69364.

Figure 18: The effect of ApoE on proliferation of mouse endothelioma-END2 cells in culture was studied. The proliferation assay of END2 cells was performed as Example  
10 7 using 20,000 cells per well and in the presence of 0.5% FCS, and the indicated concentrations of met-apoE.

Figure 19: The effect of ApoE on the proliferation of BAEC and CHO cells was studied. The proliferation of BAEC  
15 and CHO cells performed with 30,000 cells/ml in the presence of 0.5% FCS and the indicated concentrations of met-apoE as described in Example 2.

Figure 20: The effect of ApoE on the proliferation of  
20 BAEC and neuroblastoma cells was studied. The proliferation of BAEC and neuroblastoma N18TG2 was performed with 20,000 cells per ml in the presence of 0.5% FCS and the indicated concentrations of met-apoE (20A) and the ApoE-peptide 348 (20B) as described in Example 2.

Figure 21: The heat-stability of the anti-proliferative activity of ApoE was examined. The proliferation of BAEC  
25 cells (30,000 cells/ml) was tested in the presence of 0.5% FCS and the indicated concentrations of unheated or heated (100°C for 1hr) met-apoE as described in Example 2.  
30

Figure 22: The effect of serum concentration on the anti-proliferative activity of met-apoE was studied. The proliferation of BAEC cells was measured at 0.5% and 2.5%  
35 FCS and in the presence of the indicated concentrations of

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ApoE without the addition of exogenous growth factors. Met-apoE exhibits a lower degree of inhibition at the higher serum concentration as described in Example 2.

5     **Figure 23:**     The effect of the ApoE designated apoE6-2 on the proliferation of END-2 cells was studied. The proliferation of END-2 was measured as indicated in Figure 18 in the presence of 0.5% FCS and the indicated amounts of the ApoE polypeptide fragment encoded by plasmid pTVR6-2  
10     (Figure 17) as described in Example 8.

15     **Figure 24:**     The effect of serum concentration on the anti-proliferative activity of an ApoE polypeptide was studied. The proliferation of BAEC cells was measured at 0.5% and 2.5% FCS and the indicated concentrations of the ApoE polypeptide apoE6-2 as described in Example 8.

20     **Figure 25:**     The reversal of heparin activity by ApoE was studied. ApoE has a high affinity for heparin, and this property of ApoE was studied by the effect of met-apoE on a complex consisting of heparin, antithrombin III and thrombin. Addition of ApoE to the complex reverses the heparin activity resulting in inhibition of the antithrombin activity of heparin. A nonreactive short peptide designated  
25     peptide 185 was used as a negative control. A second negative control [ctrl (-)] did not include any ApoE. A positive control [ctrl (+)] did not contain heparin. The results indicate that at the ApoE concentration at which there is 50% inhibition of thrombin activity, there is  
30     about a 3:1 ratio of heparin:ApoE, i.e. 2-3 molecules of heparin are bound by each molecule of ApoE.

Detailed Description of the Invention

5 The present invention provides a method of inhibiting actively proliferating cells comprising contacting actively proliferating cells with an amount of Apolipoprotein E (ApoE) effective to inhibit proliferation. Inhibition of proliferation means reduction of the rate of proliferation of the cells.

10 The cells may be smooth muscle cells, endothelial cells e.g. aortic or corneal endothelial cells, or tumor cells, e.g. human melanoma cells, mammary tumor cells, human sarcoma cells, or carcinoma cells. Other actively proliferating cell types known to those skilled in the art are also encompassed  
15 by the methods of the invention.

A composition for inhibiting the proliferation of actively proliferating cells comprising Apolipoprotein E and a suitable carrier is also provided.  
20

Additionally, a method is provided of treating a subject suffering from excessive cell proliferation which comprises administering to the subject a amount of Apolipoprotein E effective to inhibit the excessive cell proliferation. Such  
25 a method may involve administration of the Apolipoprotein E in conjunction with other therapeutic means such as a chemotherapeutic agent or irradiation treatment, i.e. administration of ApoE prior to, during or after the other therapeutic means. Other therapeutic means for use in  
30 conjunction with Apolipoprotein E are known to those skilled in the art and are also encompassed by the methods of the invention.

A pharmaceutical composition is provided which comprises  
35 Apolipoprotein E in an amount effective to inhibit excessive

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proliferation and a pharmaceutically acceptable carrier.

In one embodiment, excessive cell proliferation is a tumor.

5       The term "Apolipoprotein E" (ApoE) as used herein encompasses any polypeptide, regardless of source e.g. naturally occurring or recombinant which includes the sequence of naturally occurring apoE necessary for the biological activity of inhibiting proliferation of cells,  
10       and mutants whose sequence varies by one or more, typically less than ten amino acids provided that such mutants have the biological activity of inhibiting proliferation of cells.

15       Naturally occurring apoE may be obtained from plasma or serum by methods known to those skilled in the art and is available commercially e.g. Calbiochem cat. no. 178466.

20       Recombinant ApoE may be obtained from genetically engineered cells which produce recombinant ApoE. The cells may be of any strain in which a DNA sequence encoding recombinant ApoE has been introduced by recombinant DNA techniques so long as the cells are capable of expressing the DNA sequence and producing the recombinant ApoE polypeptide. The cells may  
25       contain the DNA sequence encoding the recombinant ApoE in a vector DNA molecule such as a plasmid which may be constructed by recombinant DNA techniques so that the sequence encoding the recombinant ApoE is incorporated at a suitable position in the vector. The cells are preferably  
30       bacterial cells or other unicellular organisms, but eucaryotic cells such as yeast, insect or mammalian cells may also be used to produce recombinant ApoE.

35       In one embodiment the ApoE is a mutant of recombinant apoE differing from the naturally occurring polypeptide by the

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addition, deletion, or substitution of one or more non-essential amino acid residues, typically less than 10, provided that the resulting polypeptide retains the cell proliferation inhibitory activity of apoE. Persons skilled  
5 in the art can readily determine which amino acids residues may be added, deleted, or substituted (including with which amino acids such substitutions may be made) using established well known procedures, including, for example, conventional methods for the design and manufacture of DNA  
10 sequences coding for bacterial expression of mutants of the subject polypeptide, the modification of cDNA and genomic sequences by site-directed mutagenesis techniques, the construction of recombinant proteins and expression vectors, the bacterial expression of the polypeptides, and the  
15 determination of the biochemical activity of the polypeptides using conventional biochemical assays.

Examples of mutants of apoE are deletion mutants containing less than all the amino acid residues of naturally occurring  
20 apoE, substitution mutants wherein one or more residues are replaced by other residues, and addition mutants wherein one or more amino acids residues are added to the polypeptide. All such mutants share the cell proliferation inhibitory activity of naturally occurring apoE.

25 Polypeptides having substantially the same amino acid sequence as naturally occurring apolipoprotein E encompass the addition or deletion of fewer than four amino acids at the N-terminus of the amino acid sequence of the  
30 polypeptide. There may be additional substitutions and/or deletions in the sequence which do not eliminate the cell proliferation inhibiting biological activity of the polypeptide. Such substitutions and deletions are known to those skilled in the art. Substitutions may encompass up to  
35 about 10 residues in accordance with the homologous or

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equivalent groups described by e.g. Lehninger, Biochemistry, 2nd ed. Worth Pub., N.Y. (1975); Creighton, Protein Structure, a Practical Approach, IRL Press at Oxford Univ. Press, Oxford, England (1989); and Dayhoff, Atlas of Protein Sequence and Structure 1972, National Biomedical Research Foundation, Maryland (1972).

In a particular embodiment, the ApoE is recombinant met-apoE, e.g. a recombinant polypeptide comprising the sequence of naturally occurring apoE with an additional methionine at the N-terminus.

Also encompassed by the term "Apolipoprotein E" are polypeptide fragments of recombinant ApoE and of naturally occurring apoE which exhibit the cell proliferation inhibitory activity of apoE. One example of such a fragment is a 15-mer fragment disclosed in U.S. Patent No. 5,177,189, issued January 5, 1993.

Additional examples of such polypeptide fragments have amino acids 1-217 or 1-185 of naturally occurring apoE. A particular embodiment of an ApoE polypeptide having amino acids 1-217 of naturally occurring apoE is encoded by plasmid pTVR6-2 (Figure 17) which was deposited in E. coli 4300 on July 26, 1993 with the American Type Culture Collection, 12301 Parklawn Drive, Rockville, Maryland under Accession No. 69364. Another fragment is the 22KD N-terminal ApoE polypeptide produced by thrombin digestion of naturally occurring apoE or recombinant met-apoE.

Similar ApoE polypeptides may be obtained by those skilled in the art from plasmids constructed on the basis of any of the above described plasmids and their use is encompassed by the claims defining the invention. Procedures for constructing such plasmids and obtaining such polypeptides

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are well known to those skilled in the art and are described in numerous publications including Sambrook, Fritsch and Maniatis, Molecular Cloning: A Laboratory Manual, 2nd edition, Cold Spring Harbor Laboratory Press, USA (1989).

5

In sum, the method of the present invention may be practiced with any ApoE having at least substantially the same cell proliferation inhibitory activity as naturally occurring apoE.

10

Further, the invention provides in vitro methods of inhibiting DNA synthesis of proliferating cells. This method comprises contacting the cells with ApoE in an amount effective to inhibit DNA synthesis. The invention also provides in vitro methods of inhibiting the chemotactic response of endothelial cells. This method comprises contacting cells with ApoE in an amount effective to inhibit the chemotactic response.

15

20

As used herein, chemotactic response means the migration of cells in response to a stimuli. The present invention provides a method whereby cells induced to migrate by exposure to a growth factor are inhibited by the contacting of ApoE with the migrating cells. The amount effective to inhibit a chemotactic response is any amount effective to inhibit the migration of cells stimulated in response to a growth factor.

25

30

It is herein disclosed that ApoE inhibits proliferation of various mammalian cells including aortic and corneal endothelial cells and mammary carcinoma cells, melanoma, and smooth muscle cells. As used herein, carcinoma refers to a malignant epithelial tumor. Furthermore, since ApoE inhibits aortic endothelial cells, it will likely inhibit neovascularization. Without neovascularization, i.e., the

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formation of new blood vessels, cells cannot actively proliferate. In the case of tumor cells, inhibition of neovascularization results in inhibition of proliferation and thus interferes with tumor growth. Consequently, administration of ApoE is a novel treatment for the inhibition of the formation of new blood vessel growth (angiogenesis), with concomitant inhibition of tumor cell growth, and metastasis. Thus both indirectly by inhibition of angiogenesis, and directly, ApoE inhibits proliferation of a wide range of tumor cells including melanoma, sarcoma, lymphoma and leukemia cells.

It is herein disclosed that ApoE inhibits proliferation of smooth muscle cells. The formation and progression of plaques and metastatic tissue, due to abnormal neovascularization, is accompanied by the migration of smooth muscle cells to the site of the plaque or the metastatic tissue. Inhibition of proliferation of smooth muscle cells may interfere with the progression of formation of plaques and metastatic tissue.

Furthermore, abnormal neovascularization of smooth muscle cells may lead to the formation of a sarcoma. As used herein, sarcoma refers to a soft tissue tumor. Thus, treatment by ApoE for the inhibition of proliferating smooth muscle cells is also provided, thus constituting a treatment for the modulation of the formation and progression of plaques, metastatic tissue, and sarcoma tumors.

It is additionally provided that ApoE may be used therapeutically as an inhibitor of blood vessel formation for treatment of subjects suffering from disorders characterized by abnormal neovascularization. Abnormal neovascularization means the increased and enhanced ability to form blood vessels. Examples of abnormal

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neovascularization include such disorders as neovascular glaucoma, diabetic retinopathy, rheumatoid arthritis (Folkman, et al., 1989) and hemangioma.

5 In the mammalian body, cells may be actively proliferating because they are tumor cells or because they are being stimulated by endogenous or naturally occurring growth factors, or serum factors, or for other reasons.

10 Preferably, the ApoE is administered in a pharmaceutically acceptable carrier. Pharmaceutically acceptable carrier encompasses any of the standard pharmaceutical carriers such as sterile solution, tablets, coated tablets and capsules. Typically such carriers contain excipients such as starch,  
15 milk, sugar, certain types of clay, gelatin, stensic acid, talc, vegetable fats or olis, gums, glycols, or other known excipients. Such carriers may also include flavor and color additives and other ingredients.

20 Compositions comprising such carriers are formulated by well known conventional methods. However, a composition comprising ApoE in an amount effective to inhibit proliferation of actively proliferating cells was previously unknown.

25 In the method of this invention, the administration of the ApoE-containing composition may be effected by any of the well known methods, including but not limited to, oral, intravenous, intramuscular, and subcutaneous administration.

30 In the practice of the method of this invention, the amount of Apolipoprotein E incorporated in the composition may vary widely. The amount of ApoE effective to inhibit cell proliferation is 0.1mg - 1g ApoE. The precise amount and  
35 the frequency of administration of the dose will readily be

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determined by one skilled in the art, based on the characteristics of the formulation, body weight and condition of the subject, tumor size, route and frequency of administration, and the characteristics of the particular

5     Apolipoprotein E to be used.

EXAMPLES

5 This invention is illustrated by the Examples which follow.  
These Examples present specific embodiments and are set  
forth to aid in an understanding of the invention but are  
not intended to and should not be construed to limit in any  
way the invention as set forth in the claims which follow.

Example 1.Methods and MaterialsA. Methods and Materials used to measure cellular growth

5 Cellular growth was evaluated under different growth conditions and by various methods, including DNA synthesis (mitogenesis) by measuring incorporation of <sup>3</sup>H-thymidine into DNA, and proliferation, by directly quantitating cell numbers by their associated enzymatic activity.

10

Polypeptides

Recombinant met-apoE contains the amino acid sequence of the human ApoE3 isoform with an additional N-terminal methionine  
15 (Vogel, et al. PNAS 1985) and was produced as described in section B below.

Plasmatic apoE was kindly provided by S. Eiesenberg (Laboratory of Lipids, Hadassa Medical School, Ein Kerem,  
20 Jerusalem). It was isolated from plasma lipoproteins derived from healthy human volunteers homozygous for the E3 isoform and as described earlier (Rall S.C. et al, Methods In Enzymology 128:273 (1986)).

25 The ApoE designated ApoE6-2, spanning amino acids 1-217 of apoE was produced as described in Example 8.

The ApoE designated peptide 348, a tandem dimeric peptide spanning amino acids 141-155 of apoE was prepared as  
30 described in Example 2.

The ApoE produced by thrombin digestion of apoE which removes the C-terminus, may be produced as described in Example 8.

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Recombinant TSP18 is an 18 Kd polypeptide fragment, and recombinant TSP28 a 28 Kd polypeptide fragment, both of which contain the heparin binding domain comprising amino acids 1-174 and 1-242, respectively of human thrombospondin.

5

rFN33 is a recombinant 33 kD polypeptide fragment of the cell binding domain of human fibronectin comprising amino acids 1329 - 1722, but deleted of amino acids 1600-1689. The plasmid designated pFN 137-2 which encodes for the 33 kD polypeptide fragment has been fully described in co-assigned patent application U.S. Serial No. 291,951, filed December 29, 1988, and has been deposited in Escherichia coli strain A4255 under ATCC Accession No. 67910.

15

The recombinant polypeptides listed above were stored lyophilized at -70°C.

Met-apoE was reconstituted by first dissolving in distilled water at a concentration of 2mg/ml followed by the addition of 0.1 volumes of 10X PBS. rFN33 was dissolved in distilled water at a concentration of 3.5-5 mg/ml. rTSP 18 and 28 were first dissolved in distilled water at 0.5 mg/ml, desalted on a PD10 column (Pharmacia #170851-01) that was equilibrated with 10 mM sodiumbicarbonate pH 9.5, and then eluted with the same buffer. One tenth the volume of a solution of 10X PBS was then added. Polypeptide samples were stored in small aliquots at -20°C and used within one month. Heparin (Sodium, injection USP, 1000 U/ml, 6.25 mg/ml) was supplied by Lilly.

30

#### Cell Lines and Reagents

Bovine aortic endothelial cells (BAEC), were kindly provided by Dr. E. Gallin (AFRY, Bethesda, MD), and were used at

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passages 5-10. BAEC culture was routinely maintained in low glucose DMEM, containing 10% FCS, 4 mM glutamine, 0.5 mg/ml ascorbic acid and 500 u/ml penicillin and 500 u/ml streptomycin. (Biofluids Inc., Rockville, MD).

5

Bovine corneal endothelial cells (CBEC), were kindly provided by Dr. D. Blake. (Maharry Medical College, Nashville, TN), and used at passages 2-8. CBEC culture was routinely maintained in low glucose DMEM containing 10% FCS, 4 mM glutamine, 500 u/ml penicillin, 500 u/ml streptomycin, and 2.5µg/ml Fungison (BioFluids, Rockville, MD, 20850). The media was changed every 2-3 days.

10

The human melanoma cell line A2058 cells (Todaro, et al. Proc. Natl. Acad. Sci. U.S.A., 77, 5258-5262, 1980) and the human mammary tumor cell line MDA-MB 435 (Coillean, et al., (1978) In Vitro 14, 911-915), were maintained in high glucose DMEM, containing 10% FCS, 4mM glutamine and 500 u/ml penicillin and 500 u/ml streptomycin purchased from Biofluids, Inc., Rockville, MD 20850, USA. The human smooth muscle fibroblasts (SMC) were obtained from Dr. Philip Browning of the National Cancer Institute, National Institute of Health, Bethesda, Maryland. The cells were cultured in RPMI medium containing 10% FCS, 4mM glutamine, 500 u/ml penicillin, and 500 u/ml streptomycin (purchased from BioFluids).

15

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Mouse endothelioma cells (END2) (Williams et al., Cell 57:1053 (1989)) expressing the polyoma middle-T antigen were provided by I. Voldavsky (Hadassa Medical School, Ein Kerem, Jerusalem). The END2 cells were routinely maintained in low glucose DMEM containing 10% FCS, 4mM glutamine, 500U/ml each of penicillin and streptomycin. END2 cells were normally used at 70-80% confluency after 5-8 days culture. Medium was replaced every 3-4 days. Medium components were obtained

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from Kibbutz Beit Haemek, Israel.

Chinese hamster ovary cells (CHO) and neuroblastoma N18TG2 cells (Z. Vogel, Weizmann Institute) were routinely maintained in high glucose DMEM containing 10% FCS, 2mM glutamine, and 500U/ml each of penicillin and streptomycin. Medium components were obtained from Kibbutz Beit Haemek, Israel.

#### 10     Assays

Both ApoE and bFGF are heparin-binding molecules, exhibiting high affinity for heparin and HSPG both on the cell surface and the ECM. The effect of ApoE on bFGF-stimulated growth was examined in several cell types in two separate systems: mitogenesis-by following the incorporation of [<sup>3</sup>H]thymidine into DNA; and proliferation-by measuring the actual number of cells in the culture.

#### 20     1.     Inhibition of Mitogenesis

Protocol M1:     Pre-attached, dense culture.

Cells were seeded at 10<sup>5</sup>/well in 0.5 ml of medium supplemented with 10% FCS in the inner well of a 24-well tissue culture plate. After 3 days, the cells were washed with PBS and fed with 0.5 ml of medium containing 0.5% FCS and remained in this medium for 48 hr (starvation conditions). Serum-free medium containing the tested growth effectors was then added to the wells and 22 hours later the cells were labeled for 5 hours with [methyl-<sup>3</sup>H]thymidine (86.1 ci/mmol, NEN; 2.5 µCi/well). To terminate the mitogenesis assay, the cells were washed twice with 1 ml PBS, fixed with 0.3 ml solution of methanol/acetic acid (3:1), washed twice with 0.5 ml ethanol (80%), and air-

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dried. The cells were extracted from the wells by incubation with 300  $\mu$ l trypsin/EDTA (1 hr at 37°C and 30 min at room temperature), and by the addition of 100  $\mu$ l 1% SDS. The radioactivity of the extracted material was measured in a scintillation counter.

Protocol M2: Newly-attached, medium-dense culture.

Confluent monolayers of cells in T-150 cm<sup>2</sup> flasks were washed once in PBS, and then incubated in 0.5% FCS-containing medium for 48 hours (starvation conditions). Cells were trypsinized, washed in 10% FCS-containing medium, resuspended in medium containing 0.1% BSA, and seeded in 24-well plates at  $2 \times 10^4$  cells/well in the presence of various concentrations of FCS, growth effectors, and [<sup>3</sup>H]thymidine (at the concentration indicated in protocol M1). At different time points (indicated in the figure legends), mitogenesis was terminated as described in protocol M1.

## 2. Inhibition of Proliferation

Protocol P1:  $10^5$  cells were plated into 35 mm culture dishes, in 10% FCS-containing medium, allowed to attach for 24 hours, and then refed with media containing 5% FCS and the tested growth effectors. After 72 hours, cells were detached from the plates by trypsinization, and their number monitored by a Coulter counter.

Protocol P2: This was carried out using the cell titer 96TM nonradioactive cell assay (Promega #G4000) based on the methods described in Denizot et al., J. Immunol. Meth. 89:271 (1986).  $5-30 \times 10^3$  cells were plated into each well of a 96-well culture dish in medium containing 5% FCS together with the indicated concentrations of growth effectors. After 72 hours, 15  $\mu$ l of dye solution was added to each well

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and the plates were incubated for an additional 4 hours. Then 100  $\mu$ l of solubilization solution was added and after 24 hours, the amount of dye retained by the well was examined by recording absorbency at 570 nm using an ELISA plate reader.

### 3. The END2 hemangioma model

END2 cells, grown as described above, were harvested by trypsinization at mid-confluency after 5 days in culture. The cells were then suspended in DMEM containing 10% FCS, centrifuged, resuspended in basal DMEM without serum at  $6 \times 10^6$  cells/ml (or as otherwise indicated) and kept on ice. The cells were then diluted 1:1 with an extracellular matrix composition (Matrigel, H. Kleinman, Dental Institute, National Institutes of Health). Aliquots of 0.1ml were injected into the hind leg of female Balb/C mice (20-25g). On the ninth day, the mice were sacrificed and tumor development in the injected leg was observed. The tumor appeared as a hematomatous lump of purplish color the size of which varied in correlation with the number of cells initially injected. It was found that while a full size tumor developed after injection of  $10^6$  cells, the size was markedly smaller when  $10^5$  cells were injected, and only very small tumors developed following injection with  $3 \times 10^4$  cells. Therefore, the experiments were routinely performed with  $3 \times 10^5$  cells/mouse.

### 4. Thrombin activity

Thrombin activity may be measured by the hydrolysis of a chromogenic substrate resulting in release of a colored compound essentially as described by Lotenberg (BBA, 142:556 (1983)). Briefly, thrombin is able to cleave the synthetic substrate Tos-Gly-Pro-Arg-paranitroaniline resulting in the

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release of paranitroaniline (PNA) whose concentration may be determined by absorbance at 405nm.

B. Production of ApoE

5

I. Host-Vector System For Expression of Recombinant ApoE

The preferred host-vector system used for production of met-ApoE is E. coli strain W1485 (ATCC No. 12435) harboring  
10 plasmid pTVR 590-4; the host-vector system has been deposited with the American Type Culture Collection (ATCC) in Rockville, Maryland under ATCC Accession No. 67360.

The construction of plasmid pTVR 590-4 which is described  
15 below has been fully described in co-assigned copending patent application, EPO Publication No. 303,972 (see Figure 15).

Plasmid pTVR 590-4 contains the following elements:

20

a) Origin of replication.

b) The Amp<sup>r</sup> gene in counter clockwise orientation.

25

c) In clockwise orientation and in 5' to 3' order, a truncated deo P1 promoter sequence and the lambda cI<sup>857</sup> temperature-sensitive repressor coding sequence.

30

d) In counterclockwise orientation and in 5' to 3' order, the lambda promoter, the beta lactamase promoter-ribosomal binding site, the coding sequence for ApoE and the T<sub>1</sub>T<sub>2</sub> transcription termination sequences.

35

This plasmid is a high level expressor of ApoE under the control of the strong leftward promoter of bacteriophage

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lambda ( $P_L$ ) which is thermoinducibly controlled by the constitutively expressed  $cI^{857}$  temperature-sensitive repressor also situated on the plasmid. Production of ApoE from this plasmid takes place upon heat- induction at 42°C.

5

This is a so-called "host independent" expression system since the plasmid can thermoinducibly produce met-ApoE independent of prior insertion of the lambda  $cI^{857}$  gene into the host E. coli chromosome. This plasmid can therefore be used to transform a wide variety of host bacterial cells. The host described, E. coli W1485 is a prototrophic wild-type strain of E. coli freely obtainable from the ATCC under Accession No. 12435.

10

15     II. Growth of E. coli W1485 harboring plasmid pTVR 590-4 and production of a bacterial cake containing ApoE

The following description of the fermentation of E. coli W1485 harboring plasmid pTVR 590-4 is a preferred embodiment for production of a cell cake containing ApoE.

20

1. Seed Flask Development

The contents of frozen vials containing E. coli ATCC No. 12435/pTVR 590-4 are used to inoculate seed flasks containing the following medium:

25

	$K_2HPO_4$	9 g
	$KH_2PO_4$	1 g
	NaCl	5 g
30	$MgSO_4 \cdot 7H_2O$	0.2 g
	$NH_4Cl$	1 g
	FeNH <sub>4</sub> citrate	0.01 g
	Trace elements solution	1 ml
	Biotin	0.5 mg
35	Glucose	5 g

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	Ampicillin, sodium salt	0.1 g
	Deionized water	1 L
	Trace elements stock solution:	
	MnSO <sub>4</sub> .H <sub>2</sub> O	1 g
5	ZnSO <sub>4</sub> .7H <sub>2</sub> O	2.78 g
	CoCl <sub>2</sub> .6H <sub>2</sub> O	2 g
	Na <sub>2</sub> MoO <sub>4</sub> .2H <sub>2</sub> O	2 g
	CaCl <sub>2</sub> .2H <sub>2</sub> O	3 g
	CuSO <sub>4</sub> .5H <sub>2</sub> O	1.85 g
10	H <sub>3</sub> BO <sub>3</sub>	0.5 g
	Concentrated HCl	100 mL
	Deionized Water	900 mL

15 Glucose and ampicillin are added from sterile concentrated stock solutions after autoclaving the other components of the medium. The cultures are incubated at 30°C overnight on a rotary shaker at 250 rpm, and reach an OD<sub>660</sub> of 3.5-5.0.

## 2. Seed Fermenter

20 The contents of the seed flask are used to inoculate a 50 L seed fermenter containing 25-30 L of the following production medium, which contains per liter:

25	K <sub>2</sub> HPO <sub>4</sub>	8 g
	KH <sub>2</sub> PO <sub>4</sub>	2 g
	Sodium citrate	2 g
	NH <sub>4</sub> Cl	2 g
	FeNH <sub>4</sub> citrate	0.02 g
30	CaCl <sub>2</sub> .2H <sub>2</sub> O	0.04 g
	K <sub>2</sub> SO <sub>4</sub>	0.6 g
	Trace elements solution	3 mL
	(as in Section 1)	
	Antifoam	
35	(Silicolapse 5000)	2 mL

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Added after sterilization (per liter of medium)

	MgSO <sub>4</sub> .7H <sub>2</sub> O	0.4 g
	Sodium ampicillin	0.1 g
5	Glucose	40-60 g
	NH <sub>3</sub> (25-28% in water) approx.	40 mL

10 Glucose is added batchwise at inoculation; ammonia is automatically added for pH control (set point pH = 7.0) during growth.

15 The culture is cultivated at 30°C for 15-20 hours in order to achieve growth; the OD<sub>660</sub> generally reaches 20-30 during this time. This is equivalent to a dry cell weight (DCW) of 7.5-12 g/L.

3. Production Fermenter

20 The contents of the seed fermenter are used to inoculate a 750 L (nominal volume) fermenter containing about 360 L production medium as described for seed fermenter, but excluding ampicillin. The culture is cultivated at 30°C until an OD<sub>660</sub> of 10 is obtained. Induction of ApoE expression is then achieved by raising the fermenter  
25 temperature to 42°C. At induction, the following are added to the fermenter:

	DL-methionine	0.6 g per L of medium
30	Sodium acetate	5 g per L of medium

The sodium acetate (0.1% - 1%) is added to protect cells from the "toxic effect" caused by the ApoE analog.

35 The fermenter temperature is maintained at 42°C for three hours, at which time the cells are harvested. The OD<sub>660</sub> of

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the cell suspension at harvest is generally 16-20, the volume is 400-430 L and the DCW is 5.0-6.5 g/L.

#### 4. Harvest of Cells

5

The cell suspension is centrifuged at 14,000 rpm (16,000 g) in a CEPA 101 tubular bowl centrifuge at a feed rate of 250L/hr, and a cell cake weighing about 10 Kg is produced and saved. Alternatively, the cell suspension is centrifuged in a Westfalia CSA-19 continuous centrifuge at 500 L/hr. The sludge is either disrupted immediately or frozen.

10

In both cases, the supernatant contains no detectable ApoE as measured by SDS-polyacrylamide gel electrophoresis.

15

#### III. Purification of Recombinant ApoE

The following method is suitable for scale-up for industrial application and yields very pure ApoE. The general scheme of the downstream process (Scheme 1) consists of steps A through G as follows:

20

- A CELL DISRUPTION IN PRESENCE OF MAGNESIUM IONS.
- B EXTRACTION OF CELL PELLET WITH TRITON<sup>R</sup>.
- C 100K ULTRAFILTRATION.
- D DEAE CHROMATOGRAPHY
- E Q SEPHAROSE CHROMATOGRAPHY
- F CM SEPHAROSE CHROMATOGRAPHY
- G 100K ULTRAFILTRATION - TRITON<sup>R</sup> REMOVAL.

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The following detailed example of the steps in purification of ApoE was performed on 3 Kg cell cake. In addition we have successfully processed a 15 Kg cell cake using the

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methods described below with only minor modifications involving scale-up in the size of the equipment used.

5 Steps A through D were performed on 2 batches of bacterial cake, each weighing 1.5 Kg. After step D, the two batches were combined and processed as one batch through steps E to G. Steps A, B, C were performed at 4°C - 10°C, except where otherwise indicated. All other activities were performed at room temperature.

10

A. CELL DISRUPTION IN PRESENCE OF MAGNESIUM IONS

1.5 Kg of wet cell cake was suspended in 6 L of buffer A which consists of 50 mM tris/HCl, 30 mM MgCl<sub>2</sub>, 0.25% beta hydroxybutyrate sodium salt, pH=7.5. (The beta hydroxybutyrate was added as a protease inhibitor) This was then homogenized using a Kinematica homogenizer yielding 7.5 L of homogenate. Disruption was then performed using a Dynomill KDL bead mill disrupter (Willy A. Bachofen, Basel) at 5 L/hr (in two cycles). Three-fold dilution of the resulting suspension using buffer A yielded a volume of 22.5 L. This lysate contained about 6 g ApoE, i.e. about 4 g ApoE per Kg of original bacterial cake.

25 Centrifugation was then performed in a continuous CEPA-41 tubular bowl centrifuge, (Carl Padberg, Lahr/Schwarzwald) with a feed rate of 9 L/hr at 20,000 rpm (17,000 g). The pellet, weighing approximately 700 g and containing insoluble ApoE was saved and the supernatant was discarded. (Note that the ApoE is insoluble due to the presence of Mg<sup>++</sup> ions.)

30

B. EXTRACTION OF CELL PELLET WITH TRITON<sup>R</sup>

35 Six liters (1:10) of extraction buffer were added to the

-35-

pellet. (Extraction buffer: 50 mM tris/HCl, 20 mM EDTA, 0.3% Triton<sup>R</sup>, pH adjusted to 3.0 with HCl). Suspension was achieved using a homogenizer (Kinematica) at low speed. Then another 6 L extraction buffer was added (giving a final  
5 pellet:buffer ratio of 1:20) and the pH was adjusted to 4.5 with 1 N NaOH. The resulting 12 L suspension was incubated for 10 minutes at room temperature with stirring.

After incubation, the suspension was centrifuged on the CEPA  
10 41 Centrifuge at a feed rate of 20 L/hr. The pellet weighing about 450 g was discarded and the supernatant solution containing ApoE was titrated to pH=7.5 with 1 N NaOH and saved.

15 Note: Triton<sup>R</sup> is present in all following steps and is removed in step G.

C. 100 K ULTRAFILTRATION

20 The purpose of this step is to remove low molecular weight contaminants by ultrafiltration/dialysis.

A Millipore Pellicon ultrafiltration system using one 100 K cassette type PTHK was utilized to concentrate the  
25 supernatant of the previous step (about 12 L) to about 2 L. The feed pressure was 20 psig and the filtrate flow rate was 20 L/hr. The dialysis buffer was 50 mM tris HCl, 10 mM EDTA and 0.1% Triton<sup>R</sup>, pH=7.5. The 2 L retentate containing about 2-3 mg ApoE /ml was kept cool with ice.

30 The retentate was dialyzed using the recirculating mode of the Pellicon ultrafiltration system until a filtrate conductivity equivalent to that of the dialysis buffer was obtained; this was the criterion used throughout the  
35 purification for termination of dialysis.

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#### D. DEAE CHROMATOGRAPHY

The purpose of this step is to separate the ApoE from contaminants such as proteins and other cellular materials.

5

In this step a 1.6 L DEAE Sepharose Fast Flow column (Pharmacia) was used. The flow rate was 10 column volumes/hr. The capacity of the column under these conditions was determined to be 4 mg ApoE/ml. The column was first equilibrated with DEAE equilibration buffer: 20 mM tris/HCl, 1 mM EDTA, 0.5% Triton<sup>R</sup>, pH=7.5.

10

The retentate solution from the previous step (about 3 L) was then loaded on the column and washed with 3 column volumes (CV) of equilibration buffer. The first elution was performed using 3 CV of equilibration buffer containing 120 mM NaCl. Fractions were collected and the progress of the run was monitored by continuously following the absorbance of the eluate at 280 nm. The fractions were analyzed by SDS polyacrylamide gel electrophoresis stained by Coomassie Blue and the trailing edge of the peak (3.1 CV) was saved.

15

20

The second elution was performed using the equilibration buffer containing 150 mM NaCl. Fractions were collected and analyzed by SDS gel electrophoresis and most of the peak (3.9 CV) was saved. Endotoxins were measured by the Limulus Amebocyte Lysate (LAL) assay described in U.S. Pharmacopeia (U.S.P.) XXI, 1165-1166 (1985). The level of endotoxin was 3 µg per mg ApoE.

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#### Concentration and dialysis after DEAE-Sepharose

The fractions indicated from the first and second eluates were pooled and dialyzed using the Pellicon ultrafiltration system, with one 100K cassette; the dialysis buffer was 20

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mM tris/HCl, 1 mM EDTA, 0.1% Triton<sup>R</sup>, pH=7.5. The sample was concentrated to 2 L (about 2-3 mg ApoE/ml) and dialyzed.

5 E. O-SEPHAROSE (QS) CHROMATOGRAPHY

The purpose of this step is to separate active from inactive ApoE and to further remove endotoxins.

10 In this step a 1.6 L QS Fast Flow Column (Pharmacia) was used; the column capacity under these conditions was about 7 mg ApoE/ml and the flow rate was about 10 CV/hr.

15 The QS equilibration buffer was 20 mM tris/HCl, 1 mM EDTA, 0.2% Triton<sup>R</sup>, pH=7.8. After equilibration, the retentate solutions from two batches of the previous step were combined and loaded on to the column, i.e. a total volume of about 5 L of buffer containing about 5 g ApoE. The column was then washed with 2.8 CV of equilibration buffer. The  
20 first elution was performed with 3 CV of equilibration buffer containing 20 mM NaCl and the second elution was performed with about 5.5 CV of equilibration buffer containing 40 mM NaCl. Fractions were collected, monitored and analyzed as described above, and 2.0 CV were combined  
25 and saved. The level of endotoxin was measured by the LAL assay and was now less than 250 pg/mg ApoE.

Two subsequent elutions using buffer containing 70 mM NaCl and 350 mM NaCl respectively eluted the inert ApoE.

30

Concentration and dialysis after O-Sepharose

The QS-derived saved pooled fractions were concentrated and dialyzed by ultrafiltration through a Millipore Pellicon  
35 Ultrafiltration system using one 100K cassette.

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The dialysis buffer was 10 mM tris/HCl, 1 mM EDTA, 0.1% Triton<sup>R</sup>, pH=7.5. The sample was dialyzed using the recirculating mode whilst maintaining the ApoE concentration at 2-3 mg/ml. The final retentate volume was about 500 ml.

5

F. CM-SEPHAROSE CHROMATOGRAPHY

The purpose of this step is to further remove endotoxins and to lower the concentration of Triton<sup>R</sup> to 0.05%.

10

In this step a 120 ml CM-Sepharose Fast Flow (Pharmacia) column was used. The equilibration buffer was 20 mM Na acetate, 1 mM EDTA, 0.2% Triton<sup>R</sup>, pH=4.8. After equilibration, the retentate solution from the previous step was loaded on to the CM-Sepharose column. The capacity of the column was 10 mg ApoE/ml and the flow rate was 10 CV/hr.

15

The column was then washed with the following solutions: 4 CV of equilibration buffer followed by 5 CV of equilibration buffer containing 70 mM NaCl followed by 2 CV of 20 mM Na acetate, 1 mM EDTA, 0.05% Triton<sup>R</sup>, 70 mM NaCl pH=4.8. The eluate from the loading and washing steps was discarded.

20

The column was then eluted. The eluent was 8 CV of 20 mM Na acetate, 1 mM EDTA, 0.05% Triton<sup>R</sup>, 300 mM NaCl, pH=5.0. The progress of the elution was monitored by continuously following the absorbance of the eluate at 280 nm. (Two different base lines are used during the elution: one is the high U.V. absorbance buffer containing 0.2% Triton, the other is the low U.V. absorbance buffer containing 0.05% Triton. The use of a sensitivity scale of about 1.0 OD allows both buffers to appear on the chart column, the low at the foot and the high at about 0.5 OD.)

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The sample containing ApoE was immediately titrated to pH 7.8 and saved. The endotoxin level in this sample was below 50 pg per mg ApoE as measured by the LAL assay.

5      G.    100K ULTRAFILTRATION - TRITON<sup>R</sup> REMOVAL

The purpose of this step is to remove the Triton<sup>R</sup>.

10      This step was carried out at 4°C using the Millipore Pellicon Ultrafiltration System, containing one 100K cassette, pre-washed with 0.5 M NaOH overnight. The flow rate was 9-12 L/hr and the inlet/pressure was 5-10 psig. (This low flow rate is used to prevent aggregation of the ApoE as the Triton<sup>R</sup> is being removed.) The ApoE sample from  
15      the previous step (960 ml containing about 600 mg ApoE) was diluted to 0.5 mg/ml with 10 mM NaHCO<sub>3</sub> buffer pH=7.7.

The sample was then treated in the ultrafiltration system and the following conditions were applied throughout this  
20      Triton<sup>R</sup> removal step:

a)      The Triton<sup>R</sup> concentration must be lower than 0.02% i.e. the Triton<sup>R</sup> concentration must be below its critical micelle concentration in order to achieve effective  
25      Triton<sup>R</sup> removal across the 100K membrane.

b)      The ApoE must not be diluted below 0.5 mg/ml or dissociation of the ApoE molecule will occur and it may cross the 100 K membrane.

30      c)      The ApoE must not be concentrated above 1.5 mg/ml or aggregation of the ApoE molecules may occur.

The dialysis buffer used in the ultrafiltration system was  
35      10 mM NaHCO<sub>3</sub>, 150 mM NaCl, pH=7.8.

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After concentration and dilution steps in accordance with the above conditions, the dialysis was performed at constant volume and constant flow rate and the dialysis was completed when the absorbance at 280 nm of the filtrate was 0.01 units. (Triton<sup>R</sup> solution absorbs at 280 nm and an absorbance of 0.01 is equivalent to 0.0005% Triton<sup>R</sup>.) The total volume of final retentate was 770 ml and the total volume of the filtrate was 9.5 L.

The solution containing the ApoE was then filtered (0.2 micron filter) and stored at -70°C in 80 ml glass bottles.

Overall Yield:

0.3 g of highly purified met-apoE were recovered from 3 Kg of bacterial cake. The ApoE, approximately 97% pure, was in the same aggregation state as plasmatic apoE when tested under the same conditions of gel permeation analysis. The ApoE sample contained less than 50 pg of endotoxins/mg protein.

Lyophilization

If the ApoE is to be lyophilized the dialysis buffer in the Triton<sup>R</sup> removal step is 2 mM NaHCO<sub>3</sub> pH=7.8, 1mM cystein/mg apoE,, and after lyophilization the samples of ApoE are stored at -20°C.

After lyophilization, the ApoE can be redissolved and it retains its normal biological activity. The lyophilized ApoE is very stable for at least 5 years.

Example 2.      Effect of ApoE on bovine aortic endothelial  
cell cultures

A.    Effect of ApoE on incorporation of  $^3\text{H}$  thymidine

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Addition of bFGF to a freshly plated 48 hr serum-starved culture of bovine aortic endothelial cells (BAEC) stimulated the incorporation of [ $^3\text{H}$ ]thymidine by several-fold compared to the control culture, both at 1% and 2.5% FCS, as shown in Figure 1. This stimulation of DNA synthesis is strongly inhibited by addition of ApoE to the culture, and was both dose- and serum-dependent. At 1% FCS, inhibition by 0.05  $\mu\text{M}$  and 0.5  $\mu\text{M}$  ApoE was approximately 85% and 98%, respectively. However, at 2.5% FCS, the inhibition was lower, i.e., in the range of 55% and 85%, respectively.

15

Addition of another heparin-binding molecule such as the recombinant TSP fragment (rTSP 18) resulted in much less inhibition of DNA synthesis at 1% FCS. At 2.5% FCS, the inhibition by ApoE and rTSP was identical.

20

B.    Effect of ApoE on time course of thymidine  
incorporation

The effect of ApoE on the time-course of [ $^3\text{H}$ ]thymidine incorporation in a freshly plated culture of BAEC in the presence of both bFGF and 1% FCS is demonstrated in Figure 2. [ $^3\text{H}$ ]thymidine incorporation is time-dependent, reaching maximum capacity around 42 hrs after cessation of cell starvation. In the presence of 0.5  $\mu\text{M}$  ApoE, incorporation of [ $^3\text{H}$ ]thymidine was reduced by more than 95%. the residual activity (2-3%) of [ $^3\text{H}$ ]thymidine incorporation had also reached a maximum after 42 hrs. In parallel cultures, 0.5  $\mu\text{M}$  rTSP18 or rFN33 gave either 30% inhibition or no inhibition, respectively.

35

C. Effect of various concentrations of ApoE

The effect of various concentrations of ApoE on [3H]thymidine incorporation of pre-attached cultures of BAEC was measured. The example in Figure 3 demonstrates that the inhibition obtained by 5 nM ApoE in the presence of 0.5% FCS and bFGF is approximately 45%, while in the presence of FCS alone, the inhibition by the same amount of ApoE is 10-fold lower (~ 4%). It should be noted that throughout the ongoing experiments, the stimulation of cell growth by exogenously added bFGF was variable. Generally, when cells display high basal activity of [3H]thymidine incorporation at low serum concentrations (e.g., 0-0.5%), the cells are not further stimulated by added bFGF.

D. Effect of ApoE on growth factor dependent proliferation

Pre-attached cultures of BAEC plated at high density (10<sup>5</sup>/well) demonstrate a very high level of [3H]thymidine incorporation at both 0% and 0.5% FCS (as shown in Figure 4). The addition of bFGF to the cultures did not show any substantial stimulation of the [3H]thymidine incorporation. However, only cultures containing the exogenous bFGF displayed a remarkable inhibition (~ 65%) by added ApoE. When ApoE was added to the culture containing only 0.5% FCS, the inhibitory effect of ApoE was many fold lower (~ 5%), i.e. ApoE inhibits the growth factor dependent proliferation of these cells.

E. Effect of time of addition of ApoE to bovine aortic endothelial cells

Newly attached BAEC cultures were allowed to grow in the presence of bFGF and either 0.5% or 1% FCS. The addition of ApoE at time zero together with bFGF caused the maximal

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effect of inhibition. The addition of ApoE 15 or 22 hr later caused much less inhibition at both serum concentrations. The results are shown in Figure 5. Thus, the first 15 hr of growth are most effective for ApoE inhibition. After 15 hr, ApoE was considerably less effective in reducing DNA synthesis in these cultures. It should be noted that the cells became refractory to ApoE at a time prior to initiation of DNA synthesis based on the time course presented in Figure 2. Therefore, ApoE probably inhibits entry into S-phase but does not significantly arrest DNA synthesis once it is initiated.

The effect of ApoE on the proliferation of bovine aortic endothelial cells was determined in the presence of 5% FCS. Following 3 days of growth, the number of cells was examined by trypsinization and direct counting. When cells are plated in the absence of bFGF, the total increase in cell number was 10-15%, and there was no effect on cell number upon addition of ApoE. However, when bFGF was added to parallel cultures, the number of cells was increased by 2.5-fold. The addition of ApoE together with bFGF inhibited growth in a dose-dependent manner. At ApoE concentrations of 0.5  $\mu$ M, 2.5  $\mu$ M, and 5  $\mu$ M, cell growth inhibition was approximately 10%, 40%, and 50%, respectively. These proliferation results are consistent with the thymidine incorporation results in Example 2D.

The effect of ApoE on the proliferation of vascular endothelial cells from bovine aorta (BAEC) was further studied without added exogenous bFGF. The results demonstrate the inhibition by ApoE of proliferation at 0.5% with the  $IC_{50}$  around 0.15  $\mu$ M. When heated at 100°C for 60 minutes, more than 95% of the antiproliferative activity of ApoE is lost, indicating the dependence of the inhibitory activity on the native form of the ApoE molecule (Figure

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21). A similar degree of inhibition of proliferation of BAEC was also observed with apoE isolated from human plasma.

5 The specificity of the inhibition by ApoE was further demonstrated using peptide 348, a tandem dimeric peptide fragment of apoE derived from the LDL-receptor binding region and the strong heparin binding consensus sequence spanning amino acids 141-155 (LRKLRKRLRLRDADDL)<sub>2</sub> (Dyer et al., J. Biol. Chem. 266:15009 (1991) and disclosed in U.S. Patent No. 5,177,189, issued January 5, 1993. The peptide, 10 kindly provided by H. C. Krutzsch (Laboratory of Pathology, NCI, NIH) was synthesized by the standard solid phase method of Merrifield and purified as described earlier (Guo et al., PNAS 89:3040 (1992)).

15 Thus, the proliferation of BAEC cells is inhibited by met-apoE with an IC<sub>50</sub> of 0.1-0.3 $\mu$ M (Figure 20A), and by peptide 348 with an IC<sub>50</sub> of peptide 348 of 10-15 $\mu$ M (Figure 20B).

20 The inhibition of proliferation by met-apoE indicates selectivity for cell type and seems to favor vascular endothelial cells, since BAEC cells are more sensitive to inhibition than CHO cells (Figure 19) and neuroblastoma cells (Figure 20).

25 Moreover, the inhibition of proliferation of endothelial cells in the absence of exogenous bFGF is also observed at both low and high serum concentrations (Figure 22), thus indicating that the anti-proliferative activity of ApoE is 30 effectively achieved in the presence of the endogenous naturally occurring growth factors normally present in serum. Furthermore, the observation of inhibition of serum dependent proliferation in the presence of other growth factors such as EGF (Figure 7) which are not heparin 35 dependent, suggests that there are other mechanisms of

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inhibition of proliferation by ApoE.

5 In another experiment, recombinant met-apoE was compared with plasmatic apoE in the BAEC cell proliferation assay at 0.5% serum concentration. The degree of inhibition was similar except for a slightly higher degree of inhibition exhibited by recombinant met-apoE.

10 In a further experiment, the effect in the BAEC cell proliferation assay of prior treatment of purified met-apoE with guanidine chloride (GuCl) was tested. The results showed that at 0.5% FCS, the GuCl treatment caused a slight increase in the inhibitory activity of met-apoE, while at 5% FCS, GuCl treatment induced a large increase in the degree  
15 of inhibition.

Example 3. Effect of ApoE on Bovine Cornea endothelial Cells

A. Effect of ApoE where CBEC are growth factor stimulated

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The effect of ApoE on the mitogenesis and proliferation of a second type of endothelial cells, derived from bovine corneal endothelial cells (CBEc), was examined. The results are demonstrated in Figures 7 and 8, respectively. The results in Figure 7 describe the incorporation of [<sup>3</sup>H]thymidine into CBEc, as was measured on a newly attached culture following 2 days serum starvation. At 0% FCS, the incorporation of [<sup>3</sup>H]thymidine is relatively low. The incorporation is simulated several-fold when bFGF was added to the culture. The addition of met-apoE (at 0.5 μM) had dramatically reduced this bFGF-dependent DNA synthesis yielding inhibition of more than 90%. When cells are allowed to grow in the presence of 1% or 2% FCS, their initial growth was much greater and they were not stimulated by the addition of bFGF to the serum. With increasing serum concentrations, the ApoE-induced inhibition was reduced to about 50% and 35% at 1% and 2% FCS, respectively. Surprisingly, a similar mode of inhibition by ApoE was obtained with EGF-stimulated CBEc culture which is considered to be a non-heparin-binding growth factor. Here again, ApoE inhibited (>90%) the EGF-dependent growth, and to much less extent, the serum-dependent growth (45% and 25% at 1% and 2.5% FCS, respectively).

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20  
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Based on the above results, ApoE will inhibit corneal endothelial cells from other mammalian (including human) sources, especially when the cells are actively proliferating.

B. Effect of ApoE when CBEC are serum stimulated

Higher concentrations of ApoE inhibit serum-stimulated proliferation in CBEC culture. The effect of met-apoE on CBEC proliferation was measured and is shown in Figure 8. CBEC were tested for proliferation at 5% FCS and in the presence of bFGF. The proliferation by bFGF was inhibited in a dose-dependent manner, with an  $IC_{50}$   $\sim 1.5 \mu M$ . It is not clear whether the inhibition of proliferation in this case is dependent on the presence of bFGF. However, it is clear that ApoE inhibits proliferation of actively proliferating corneal endothelial cells.

C. Reversibility of ApoE inhibition

The inhibition of [ $^3H$ ]thymidine incorporation by ApoE of CBEC culture is reversible, as shown in Figure 9. This reversibility is dependent upon the amount and time at which ApoE is given to the culture. When the newly attached CBEC cultures, in the presence of 1% FCS and bFGF, are maintained for the entire length of the mitogenesis experiment (40 hr) at 1.0 and 1.5  $\mu M$  met-apoE, inhibition was 30% and 50%, respectively. However, when ApoE was given only for the first 22 hr, the inhibition by 1.0 and 1.5  $\mu M$  ApoE following 40 hr incorporation, was much lower, e.g., in the order of 5% and 15%, respectively.

D. The effect of ApoE on Protein Synthesis of CBEC

Protein synthesis in CBEC was measured following a 1 hour starvation for methionine, and administration of  $S^{35}$ -methionine (6 hours), as shown in Figure 13. When met-apoE (0.5  $\mu M$ ) was added to a parallel culture, the incorporation of  $S^{35}$ -methionine into protein was identical to the control without ApoE. For both, the incorporation was approximately

60%. Thus, addition of ApoE has no direct effect on the synthesis of proteins.

Example 4.      Effect of ApoE on Melanoma Cells

DNA synthesis in human A2058H melanoma cells was tested in a newly attached culture and in the presence of 0.5% FCS and bFGF, and following the addition of met-apoE, rTSP18 (rTSP18) and rFN33, as shown in Figure 10. Addition of ApoE at 0.5 and 1.0  $\mu$ M caused inhibition of approximately 40% and 75%, respectively. No such inhibition was observed with the other molecules added in parallel. Indeed, addition of 0.5  $\mu$ M of either TSP or FN stimulated [ $^3$ H]thymidine incorporation by 2-2.5-fold.

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Example 5.      Effect of ApoE on Carcinoma Cells

5      DNA synthesis in the human mammary carcinoma (MDA) cells was measured in a newly attached culture in 0.5% FCS and bFGF, as shown in Figure 11. Addition of 0.5  $\mu$ M met-apoE or rTSP18 inhibited [ $^3$ H]thymidine incorporation by approximately 60% and 45%, respectively. Inhibition of DNA synthesis by heparin was lower (in the range of 30%).

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Example 6.      Effect of ApoE on Smooth Muscle Cells

5      The effect of ApoE on the proliferation of human smooth  
muscle cells (SMC) was tested at 0.5% and 5% FCS. In the  
presence of 0.5% FCS and a high concentration of met-apoE (4  
10       $\mu$ M), a strong inhibition of both serum and bFGF-dependent  
proliferation of SMC was obtained (approximately 80%  
inhibition in both cases). When serum concentration was  
increased to 5% the inhibition obtained by the same  
concentration of met-apoE was lower (approximately 30% for  
both serum and bFGF-dependent proliferation). The results  
are shown in Figure 12. Thus ApoE inhibits proliferation of  
actively proliferating human smooth muscle cells.

Example 7. Effect of ApoE on Mouse Endothelioma Cells

The antiproliferative and antiangiogenic activity of ApoE was further demonstrated in vitro and in vivo using mouse endothelioma cells END2 (Williams, Cell 1989). END2 are polyoma middle T-antigen transformed mouse endothelial cells, which develop spindle shaped cells in vitro and vascular tumors and hemangiomas in vivo. These cells have been used in vivo as a model system for studying angiogenesis. Cell proliferation was assayed as described in Example 1 according to protocol P1. Met-apoE inhibited the proliferation of END2 cells in culture with an  $IC_{50}$  of about  $0.25\mu M$  at 0.5% FCS (Figure 18). Inhibition of proliferation by another ApoE is described in Example 8.

In addition, it was also demonstrated that ApoE inhibits the development of angiogenic lesions and hemangiomas in vivo in the endothelioma model. Thus, intravenous (i.v.) administration of met-apoE at a concentration of 0.4 mg/mouse, daily, for 8 days, resulted in a 40-60% reduction in the size of the hemangioma compared to the non-ApoE treated control.

Groups of ten mice were injected with the Matrigel suspension of END2 cells described above. The groups were then treated either with 0.2ml saline (control group) or 0.2ml saline containing 2mg/ml met-apoE (experimental group). The animals were sacrificed on the ninth day and the tumors were scored on a scale of 0-3 (0=no tumor). The results are shown in Table 1.

Table 1

Group	n <sup>1</sup>	Score <sup>2</sup>
Control	10	2.75±0.42
Experimental	10	1.7±0.82

5

<sup>1</sup> n=number of mice<sup>2</sup> score: mean±standard deviation

10 The results were found to be significant ( $P < 0.005$ ) according to the Wilcoxon Rank Sum Test.

Based on the above results, ApoE will be effective in treating hemangiomas in humans.

Example 8. APO E Fragments

5 As mentioned earlier, ApoE has a specific ability to bind to lipoprotein particles for directing their removal from the plasma, "reverse cholesterol homeostasis", and for mediating receptor dependent endocytosis to the liver. Due to the high numbers of lipoprotein particles contained in plasma, ApoE, upon delivery in small amounts to the site of a tumor, will  
10 bind to lipoprotein particles and will be unavailable to function as an anti-proliferative agent. Therefore, full length ApoE (e.g. met-apoE) in the presence of serum or plasma is able to inhibit proliferation of cells only upon delivery in large amounts to the tumor.

15 This deficiency may be overcome by cleavage of the apoE sequence to remove the lipid binding domain present at the carboxy terminus. Upon cleavage of apoE with a proteolytic enzyme and elimination of the carboxyl end lipophilic  
20 domain, the remaining amino terminal fragment no longer has normal affinity for binding to lipoprotein particles but still readily binds to heparin and heparan sulfate proteoglycans. Therefore smaller amounts of ApoE will suffice to obtain inhibition of cell proliferation.

25 In a particular embodiment, such an ApoE fragment may be produced from apoE containing the complete sequence of naturally occurring apoE by cleavage of the carboxyl terminus with a proteolytic enzyme generating, for example,  
30 a 22 kD fragment containing the amino terminus (Thuren, 1992). One example of a proteolytic enzyme that may be used is thrombin. Upon digestion of recombinant met-apoE by thrombin, one 22 kD and one 10 kD fragment may be obtained. The 22 kD fragment, containing the first 191 amino terminal  
35 residues, has the binding sites for manganese heparan

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sulfate and heparin and the low density lipoprotein (LDL) receptors, but has reduced ability to interact with natural lipoprotein particles.

5 An improved method of obtaining an increased amount of the free form of ApoE in the plasma and the reduction of its sequestration by lipid particles, is by production of an ApoE fragment deleted of the major lipid binding domain of apoE from the carboxyl terminus by means of recombinant DNA  
10 techniques.

In a specific embodiment, an ApoE polypeptide fragment, ApoE6-2, spanning amino acids 1-217 of apoE is encoded and expressed by plasmid pTVR6-2 (Figure 17). This 28KD MW  
15 ApoE was also tested for its effect on cell proliferation. The purification of this ApoE is similar to the purification of met-apoE as described in Example 1 with minor modifications, one of which was ultrafiltration with a 50K instead of 100K cutoff membrane. The purified polypeptide  
20 was then treated with 6M urea and dialyzed to remove the urea.

ApoE6-2 inhibited proliferation of BAEC culture with an  $IC_{50}$  around  $0.3 \mu M$  at both 0.5% and 2.5% FCS respectively (Figure  
25 24). Thus, in contrast to met-apoE, which displays a substantial reduction in activity at higher serum concentrations, ApoE6-2 is much less affected by increasing serum concentration.

30 This ApoE was also found to inhibit the proliferation of END-2 cells. The proliferation of END-2 was measured as indicated in Figure 18 in the presence of 0.5% FCS and the indicated amounts of ApoE6-2.

35 Based on these results, this and similar ApoE fragments will

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provide high antiproliferative and antiangiogenic activity  
in vivo (where serum concentration is 100%).

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Example 9.      Reversal of antithrombin activity of heparin  
by ApoE

5      In this example, the effect of ApoE on the activity of  
heparin in a heparin-antithrombinIII-thrombin complex was  
demonstrated. Heparin activates antithrombinIII which in  
turn inhibits thrombin activity. Sequestration of heparin  
from this complex by ApoE results in the inactivation of  
10      antithrombinIII and a concomitant increase in thrombin  
activity. The effect of ApoE is dose dependent (Figure 25).  
The stoichiometry of the reaction indicates that ApoE  
displays high affinity for heparin, and that one mole of  
ApoE can bind 2-3 moles of heparin.

15      Thrombin activity was assayed as described in Example 1.

To be more specific, in a total volume of 140 $\mu$ l,  
antithrombin (50 $\mu$ l at 2.9U/ml, Sigma), heparin (15  $\mu$ l, Eli  
Lilly 14KD, 0.4 USP/ml; 2 $\mu$ M final concentration in the  
20      reaction) and met-apoE (15 $\mu$ l of the indicated dilutions of  
a 60 $\mu$ M solution) were preincubated for 30 seconds. Thrombin  
(10 $\mu$ l, 20U/ml, Sigma) was then added and the reaction mix  
further incubated for an additional 30 seconds following  
which the chromogenic substrate (2 $\mu$ M, Sigma) was added. The  
25      results are shown in Figure 25. Under the reaction  
conditions used, no decrease in thrombin activity by heparin  
was observed until the met-apoE was diluted 64 fold. 50%  
inhibition of thrombin activity was achieved at  
approximately 1:100 dilution of ApoE (0.6 $\mu$ M) Therefore one  
30      molecule of ApoE can bind about 2-3 molecules of heparin.

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What is claimed is:

- 5 1. A method for inhibiting proliferation of actively proliferating cells which comprises contacting actively proliferating cells with an amount of Apolipoprotein E effective to inhibit proliferation.
- 10 2. The method of claim 1 wherein the cells are human smooth muscle cells.
- 15 3. The method of claim 1 wherein the cells are endothelial cells.
4. The method of claim 3 wherein the endothelial cells are aortic endothelial cells.
5. The method of claim 3 wherein the endothelial cells are corneal endothelial cells.
- 20 6. The method of claim 1 wherein the cells are tumor cells.
- 25 7. The method of claim 6 wherein the tumor cells are human melanoma cells.
8. The method of claim 6 wherein the cells are human mammary tumor cells.
- 30 9. The method of claim 6 wherein the cells are human sarcoma cells.
10. The method of claim 6 wherein the cells are carcinoma cells.
- 35 11. A composition for inhibiting the proliferation of

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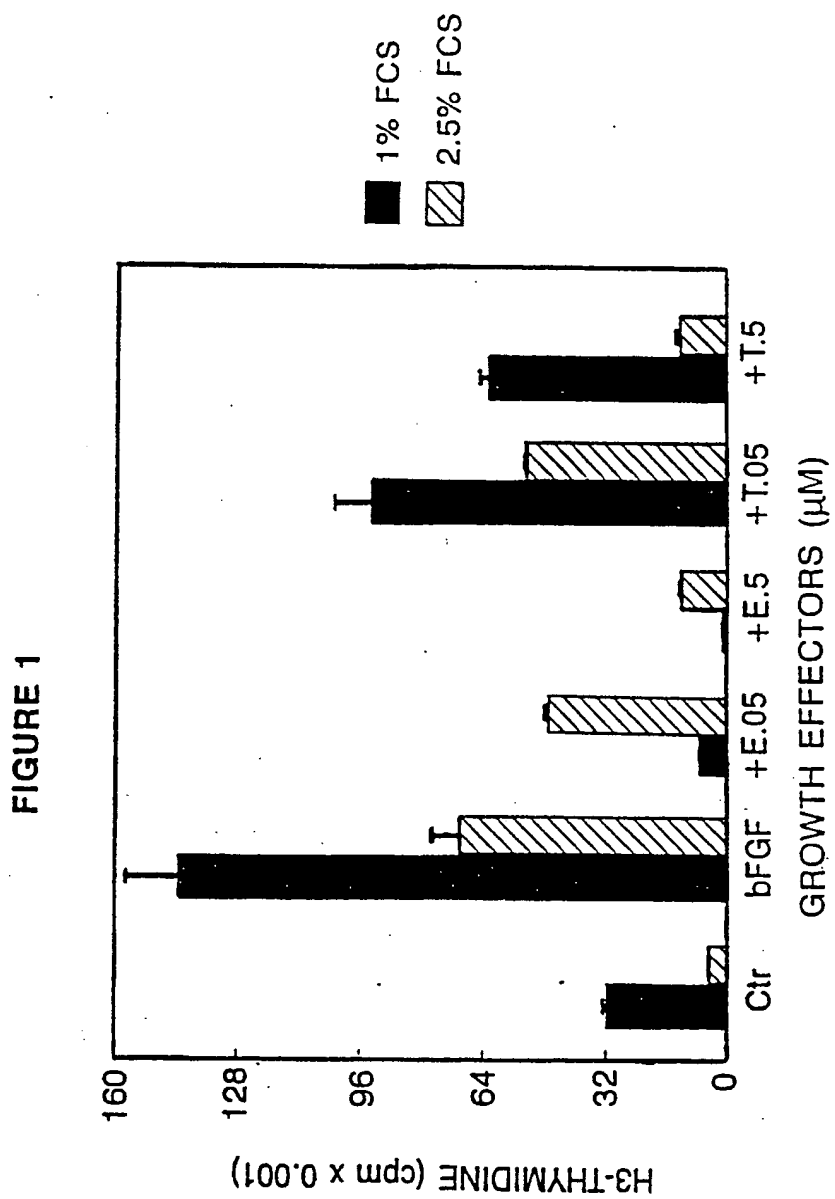
actively proliferating cells comprising Apolipoprotein E and a suitable carrier.

- 5 12. A method of treating a subject suffering from excessive cell proliferation which comprises administering to the subject an amount of Apolipoprotein E effective to inhibit the excessive cell proliferation.
- 10 13. The method of claim 12, wherein the Apolipoprotein E is administered in conjunction with a chemotherapeutic agent.
- 15 14. The method of claim 12, wherein the Apolipoprotein E is administered in conjunction with irradiation treatment.
- 20 15. The method of claim 12 wherein the excessive cell proliferation comprises a tumor.
- 25 16. The method of claim 15 wherein the tumor cells are human melanoma cells.
17. The method of claim 15 wherein the tumor cells are human mammary tumor cells.
18. The method of claim 15 wherein the tumor cells are human sarcoma cells.
- 30 19. A method according to claim 12 wherein the excessive cell proliferation comprises abnormal neovascularization.
- 35 20. The method of claim 19, wherein the abnormal neovascularization is neovascular glaucoma.

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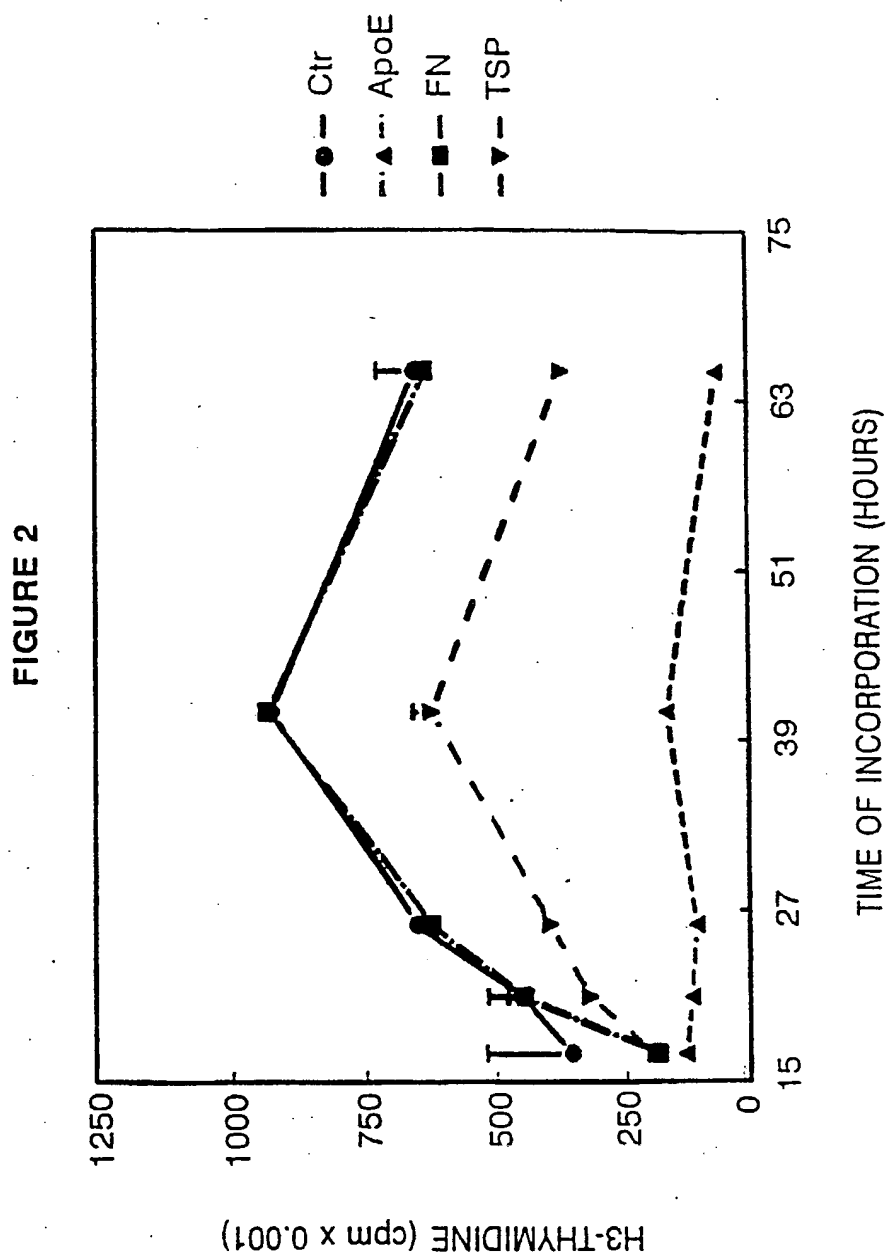
21. The method of claim 19, wherein the abnormal neovascularization is diabetic retinopathy.
- 5 22. The method of claim 19 wherein the abnormal neovascularization is present in rheumatoid arthritis.
23. The method of claim 19 wherein the abnormal neovascularization is a hemangioma.
- 10 24. The method of claim 12 wherein the Apolipoprotein E is administered intravenously.
25. The method of claim 12 wherein the Apolipoprotein E is administered subcutaneously.
- 15 26. The method of claim 12 wherein the Apolipoprotein E is administered intramuscularly.
- 20 27. A pharmaceutical composition comprising Apolipoprotein E in an amount effective to inhibit excessive proliferation and a pharmaceutically acceptable carrier.
- 25 28. The composition of claim 27 wherein the excessive cell proliferation is a tumor.

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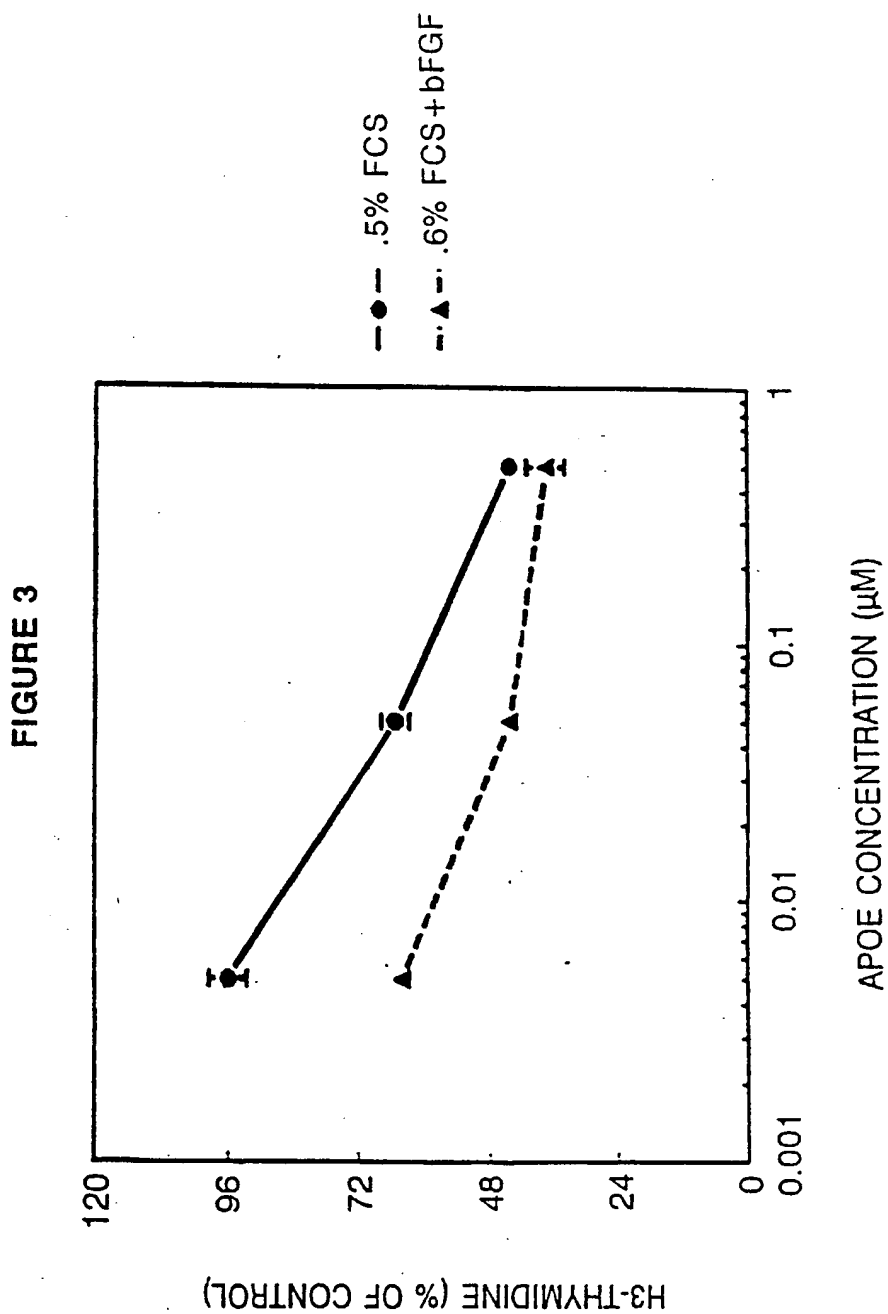
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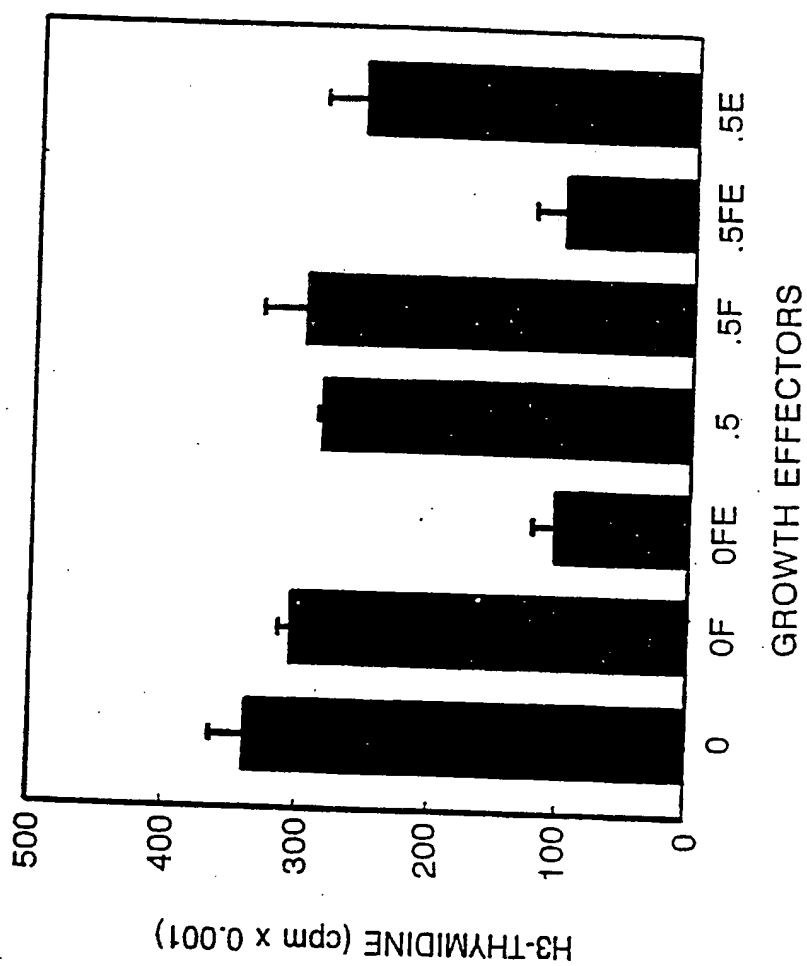
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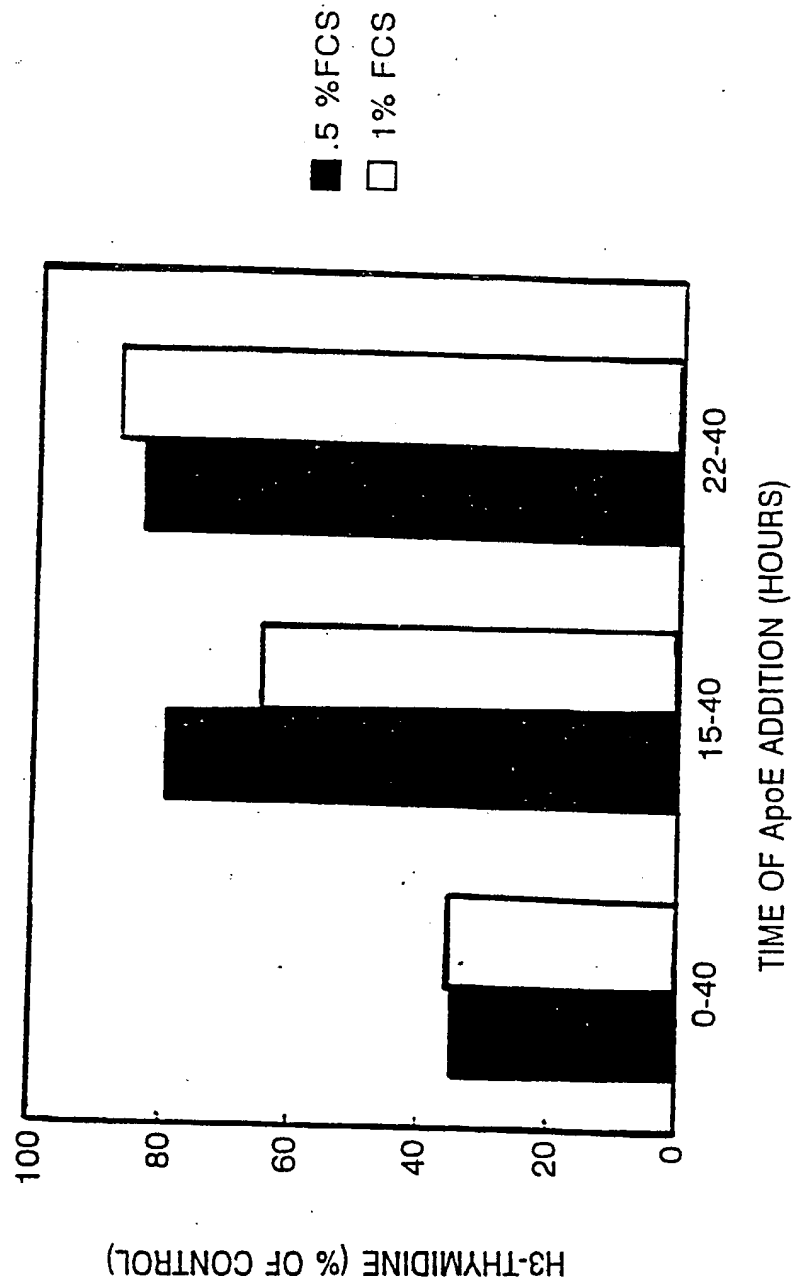
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FIGURE 4

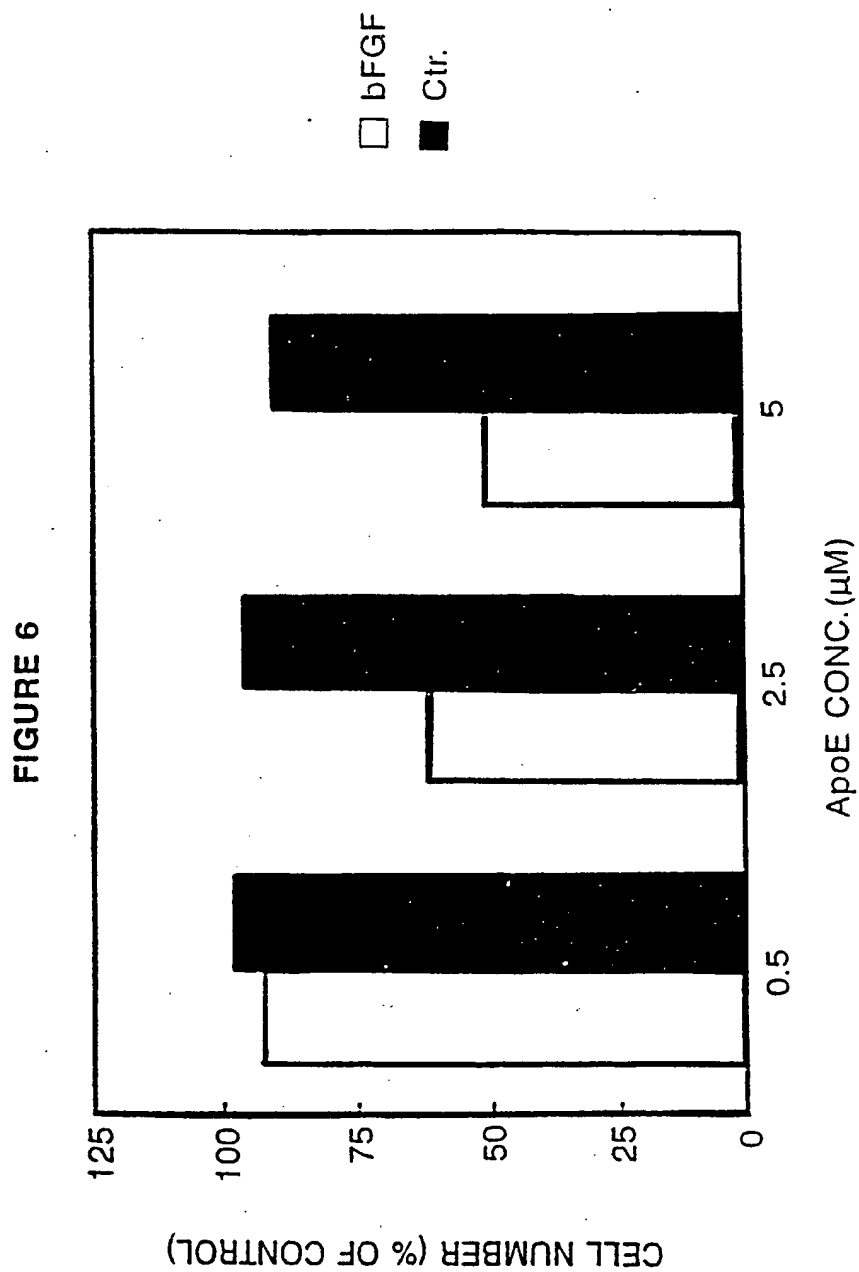


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FIGURE 5



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FIGURE 7

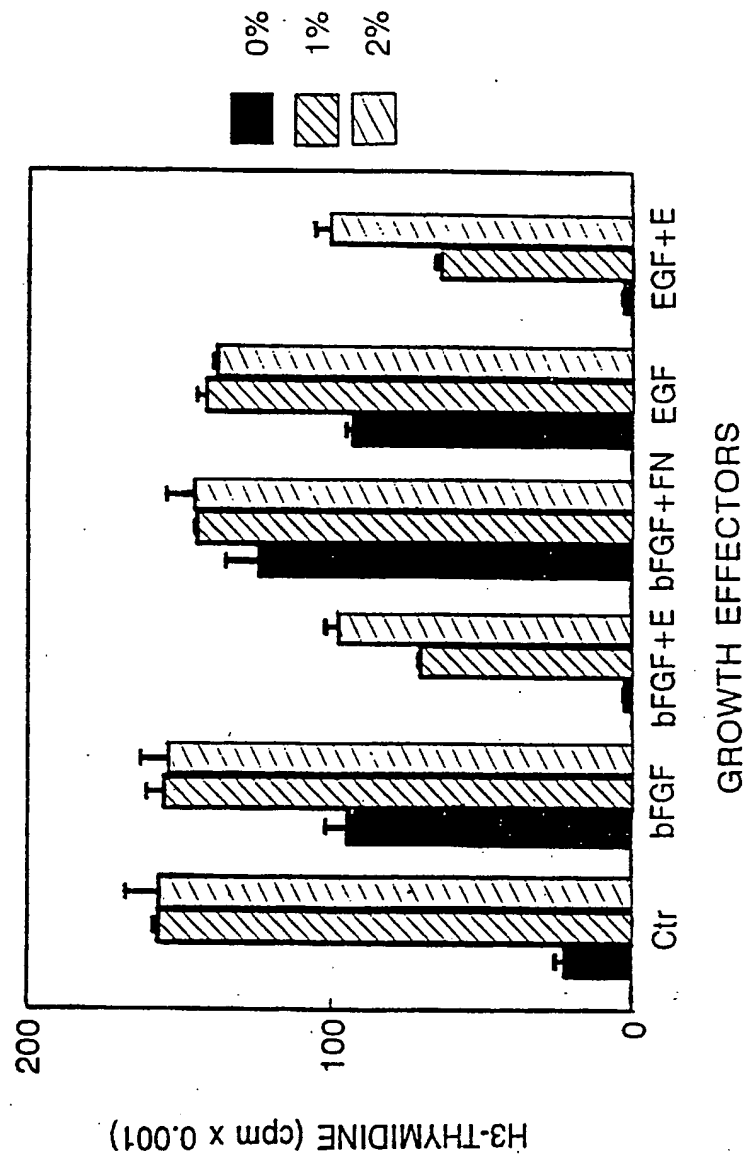


FIGURE 8

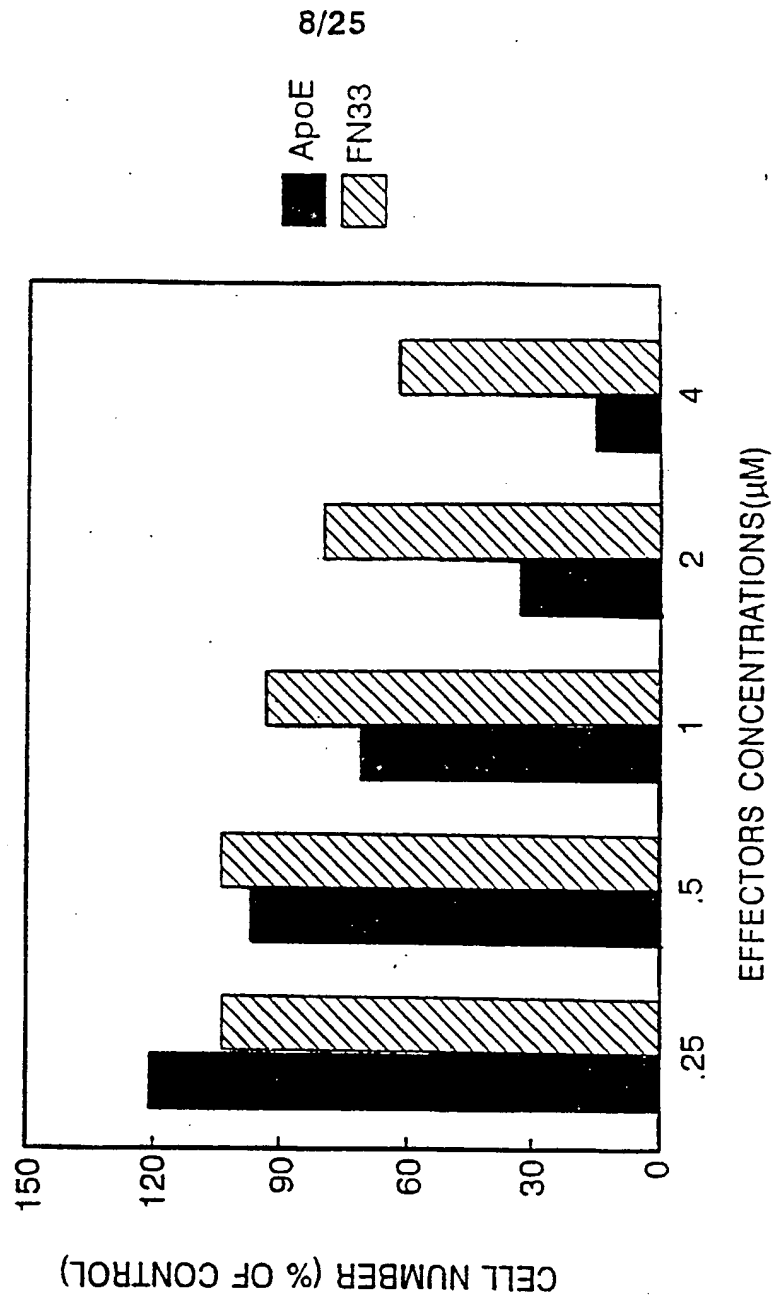
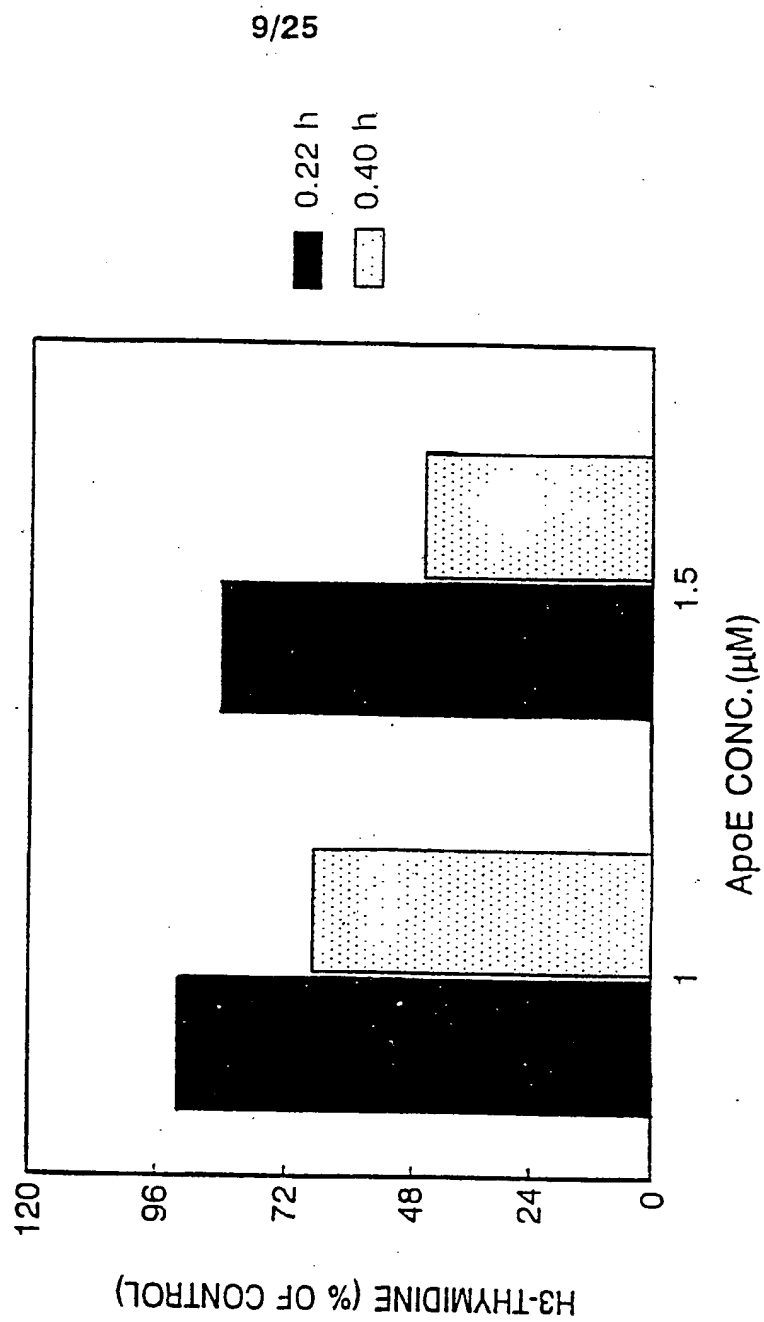
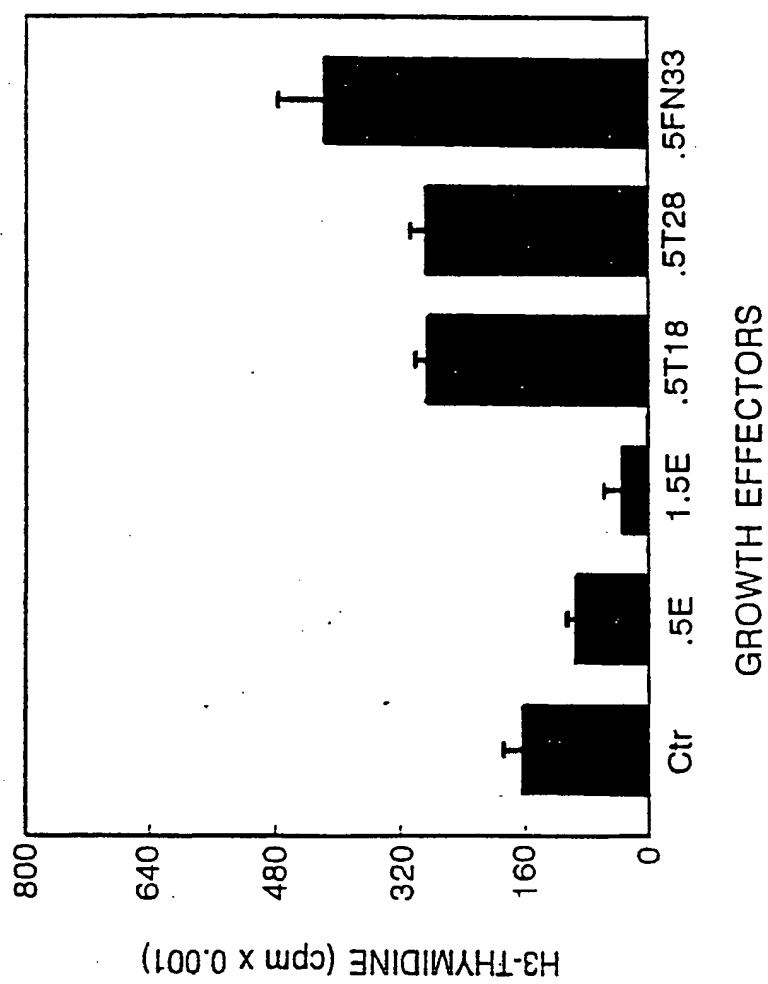


FIGURE 9



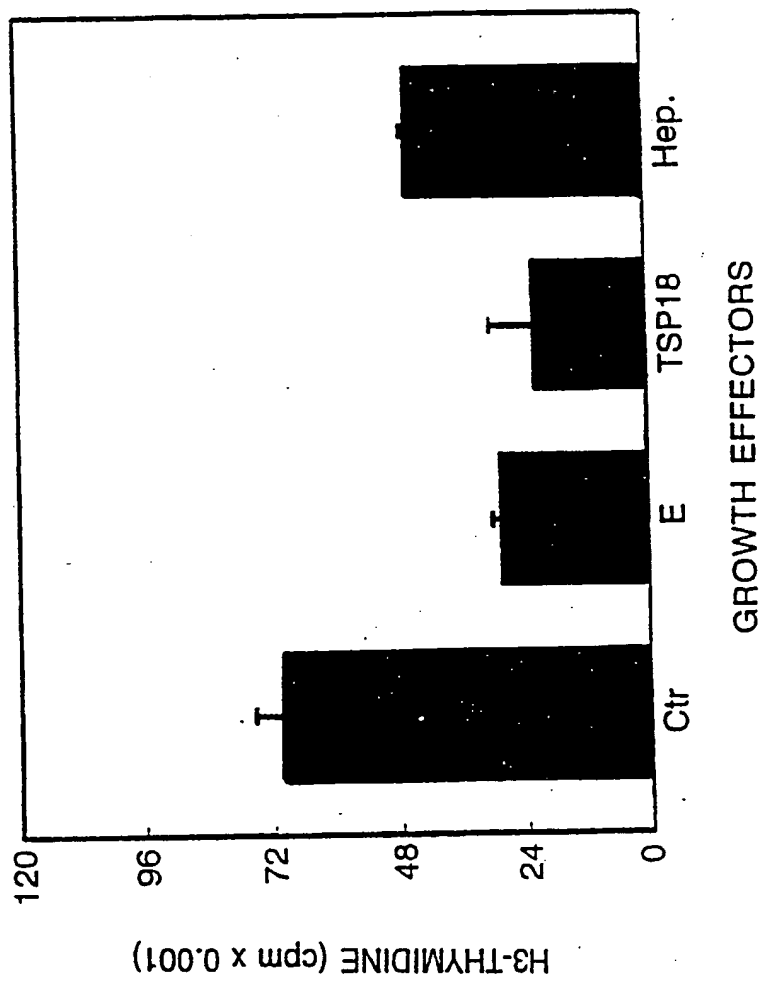
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FIGURE 10



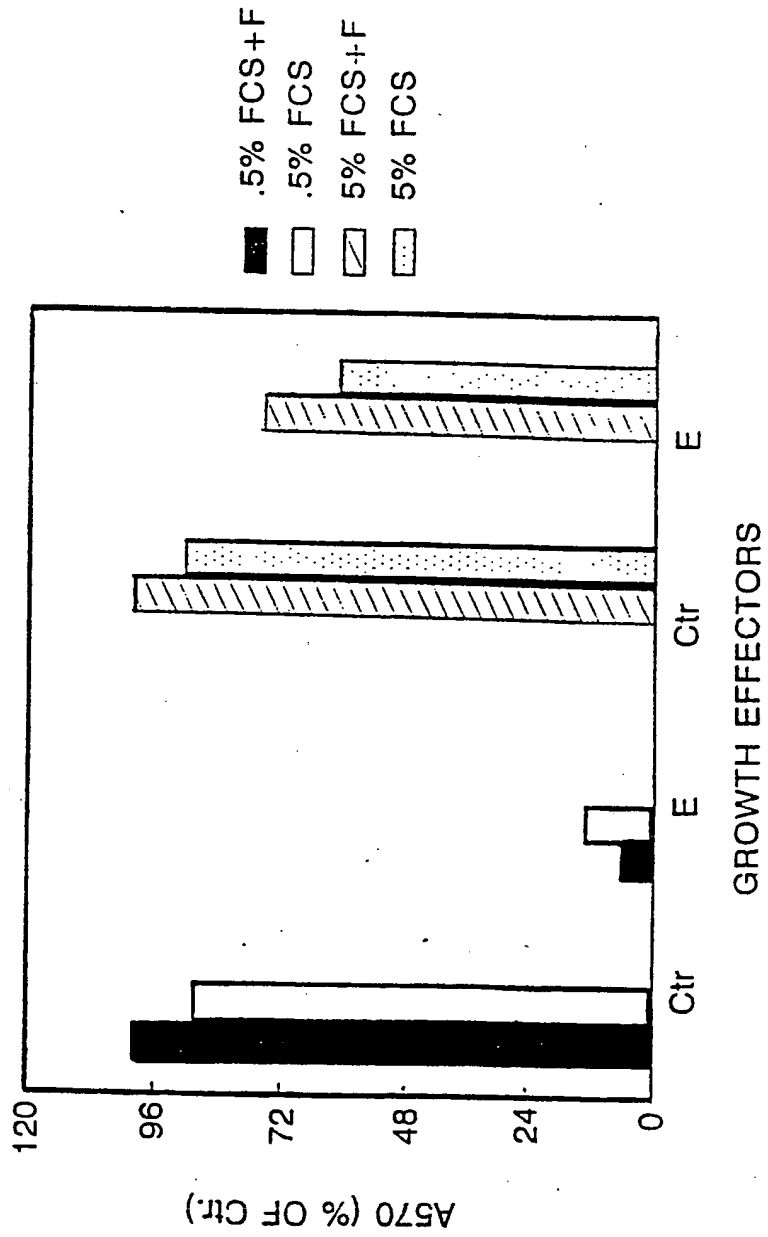
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FIGURE 11



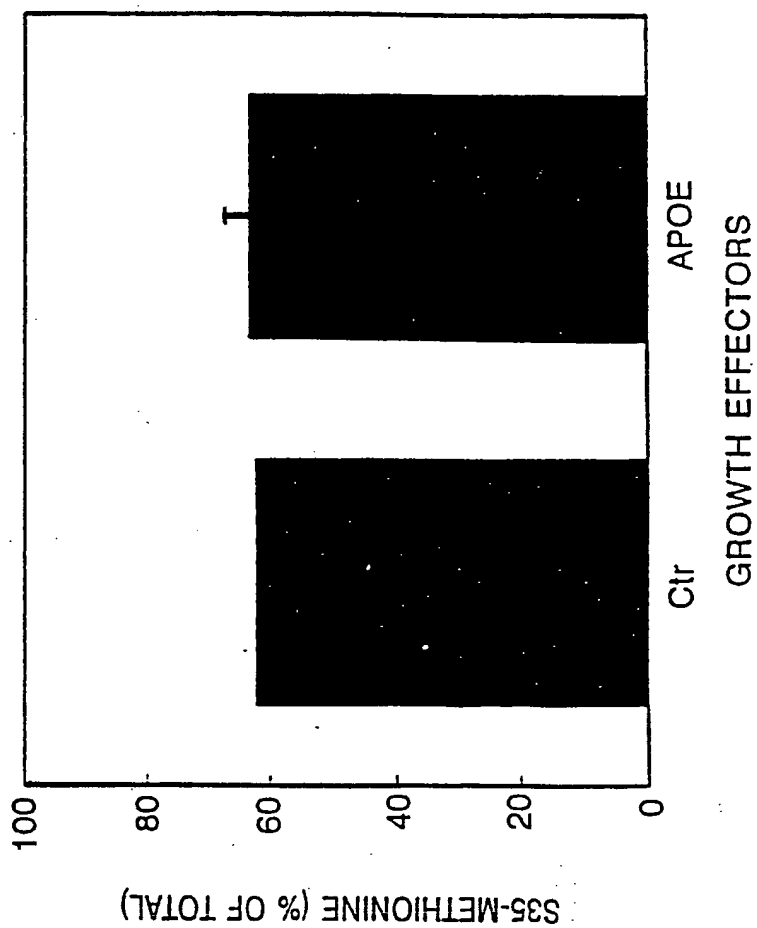
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FIGURE 12



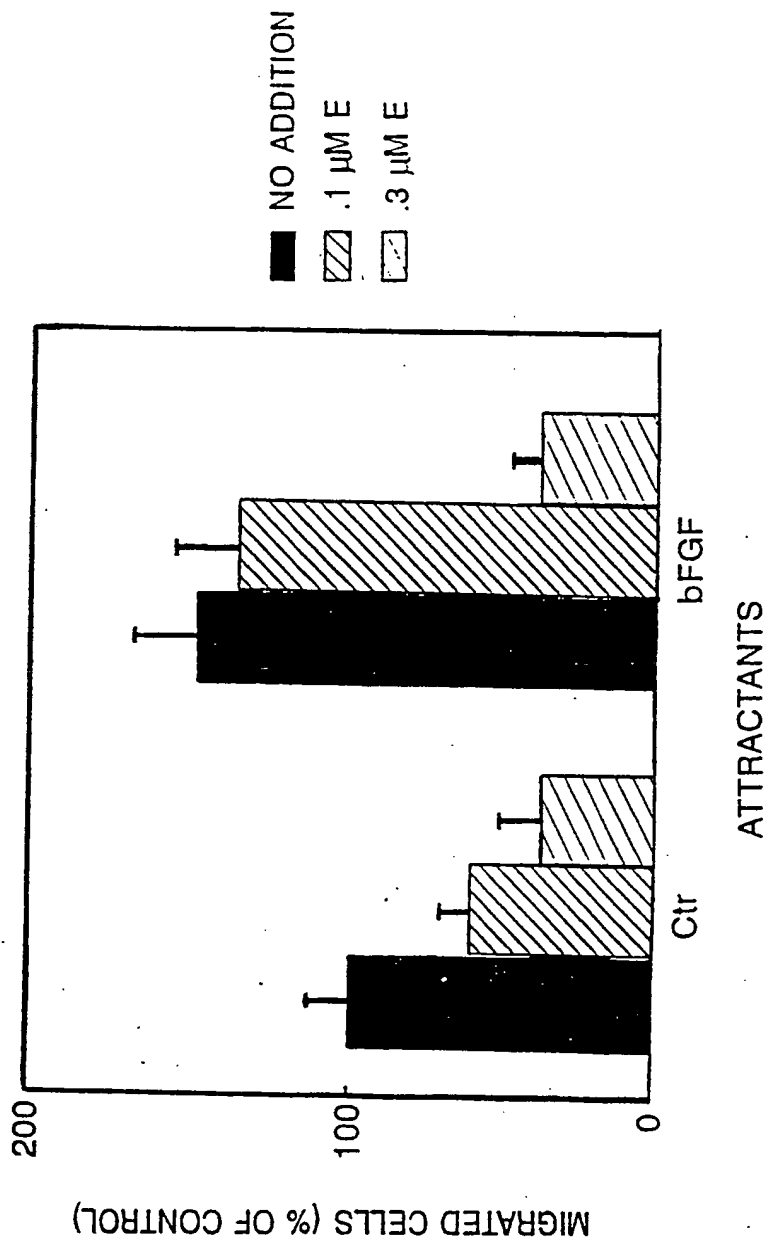
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FIGURE 13



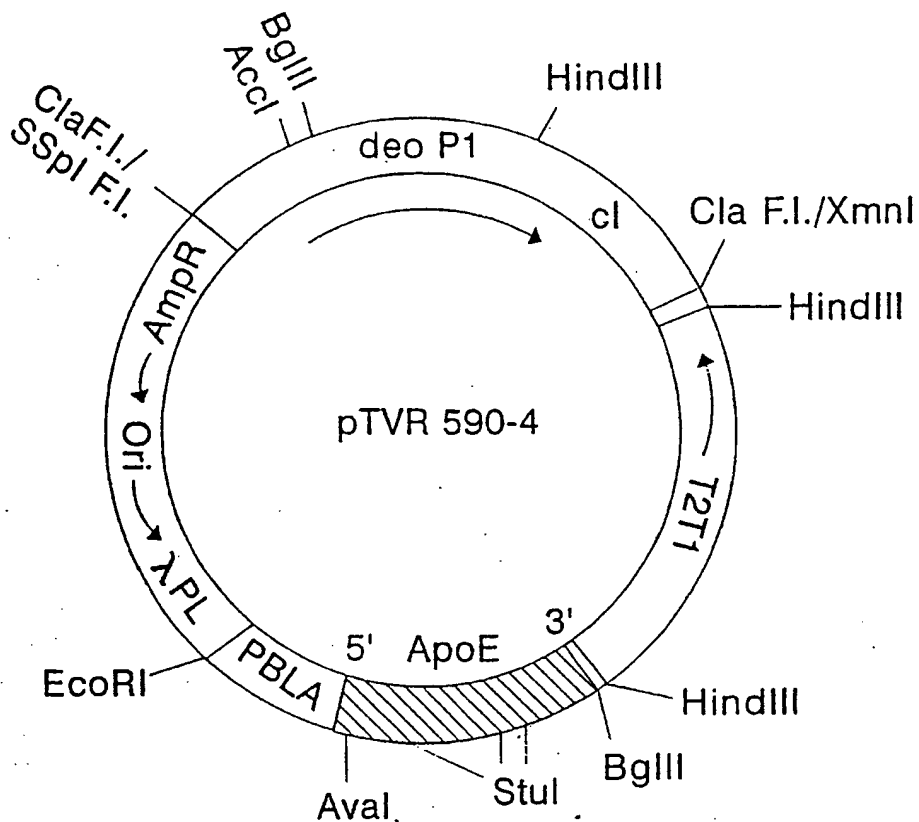
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FIGURE 14



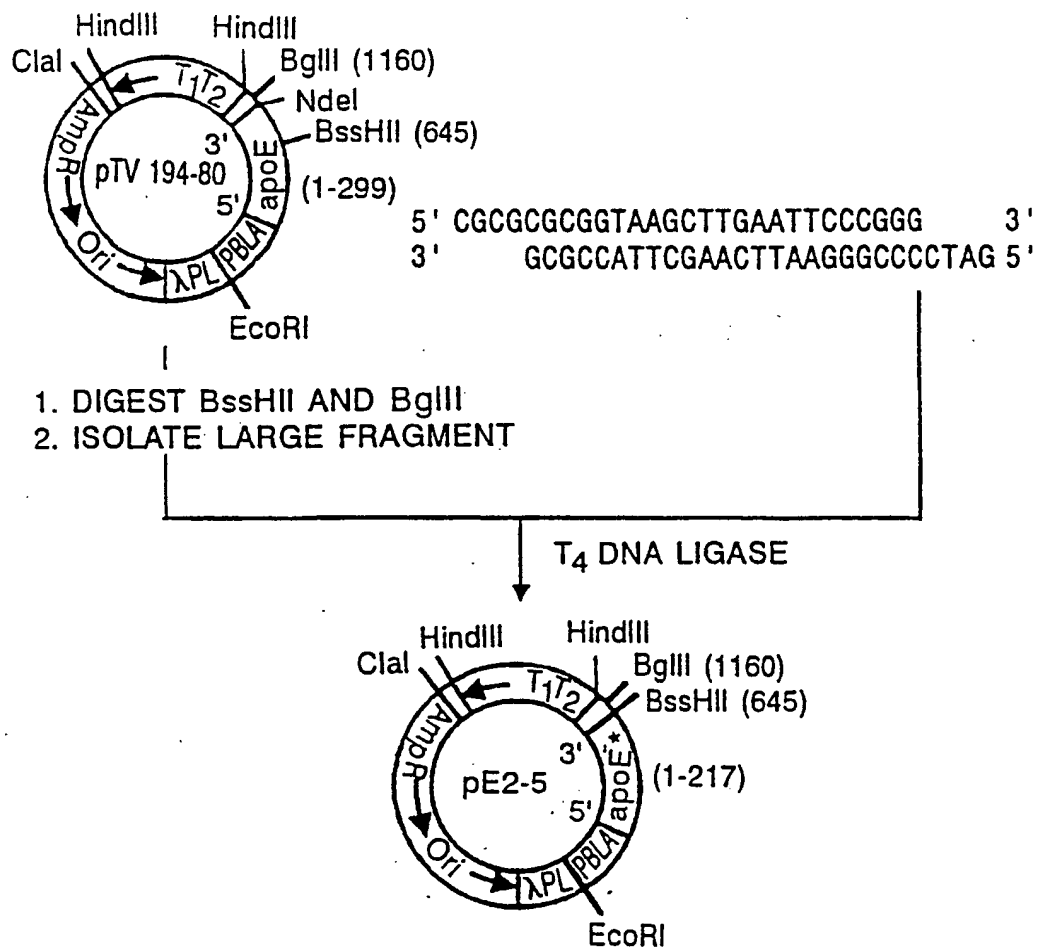
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FIGURE 15



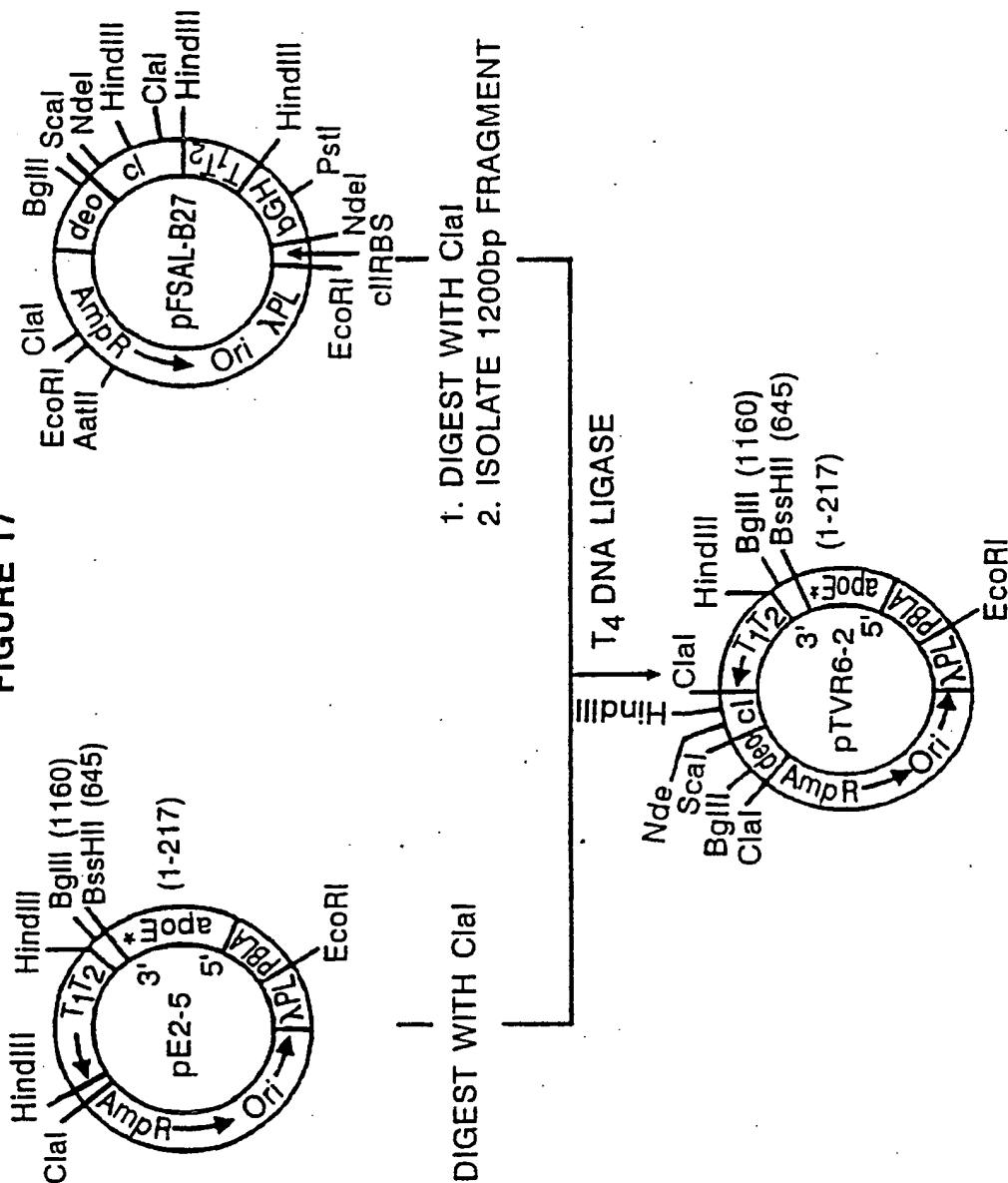
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FIGURE 16

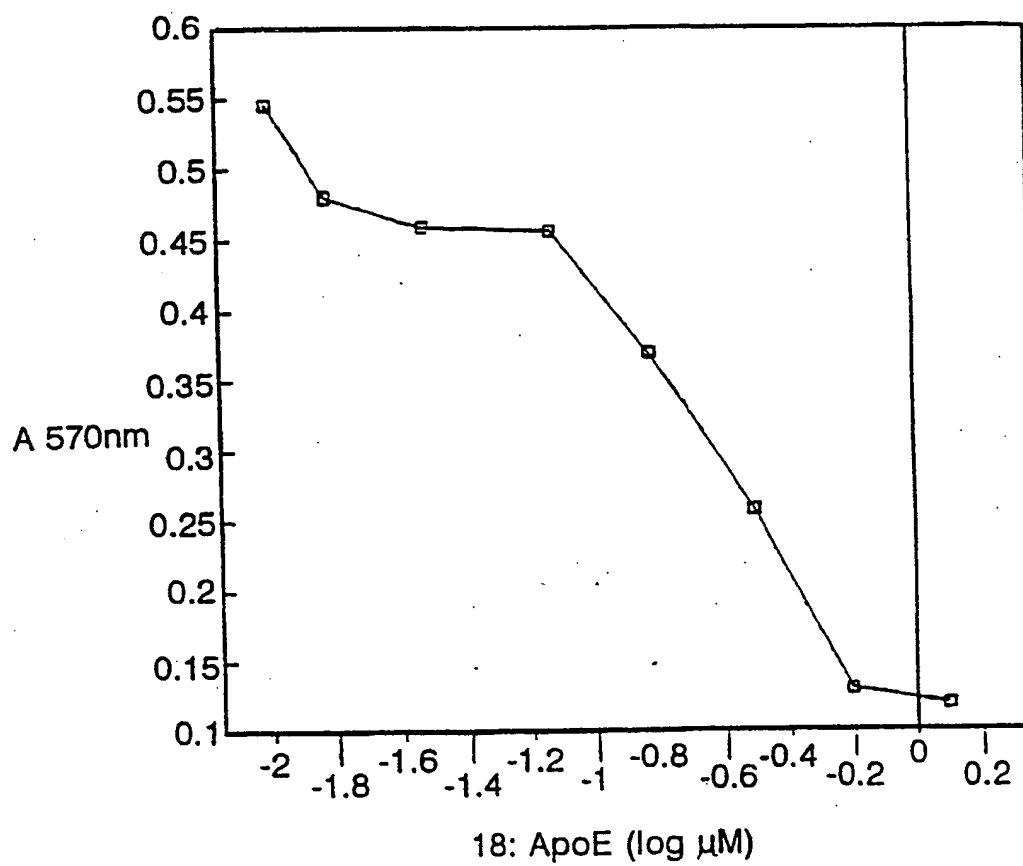


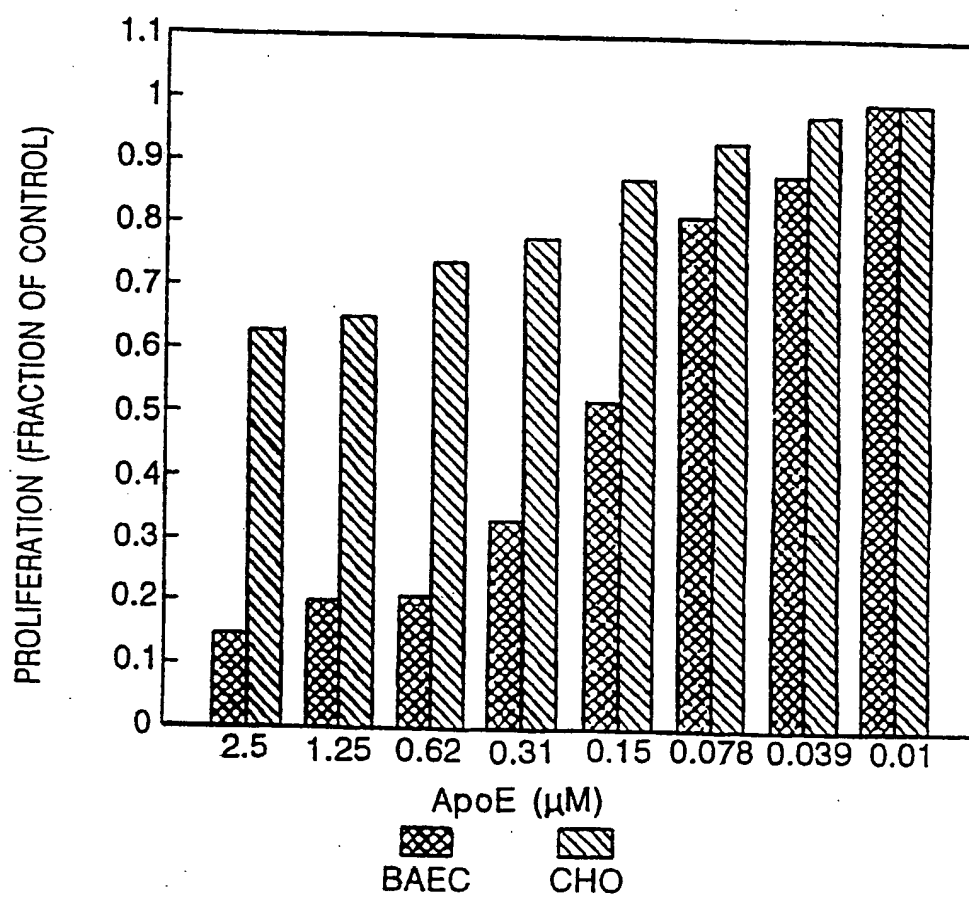
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FIGURE 17



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FIGURE 18



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FIGURE 19

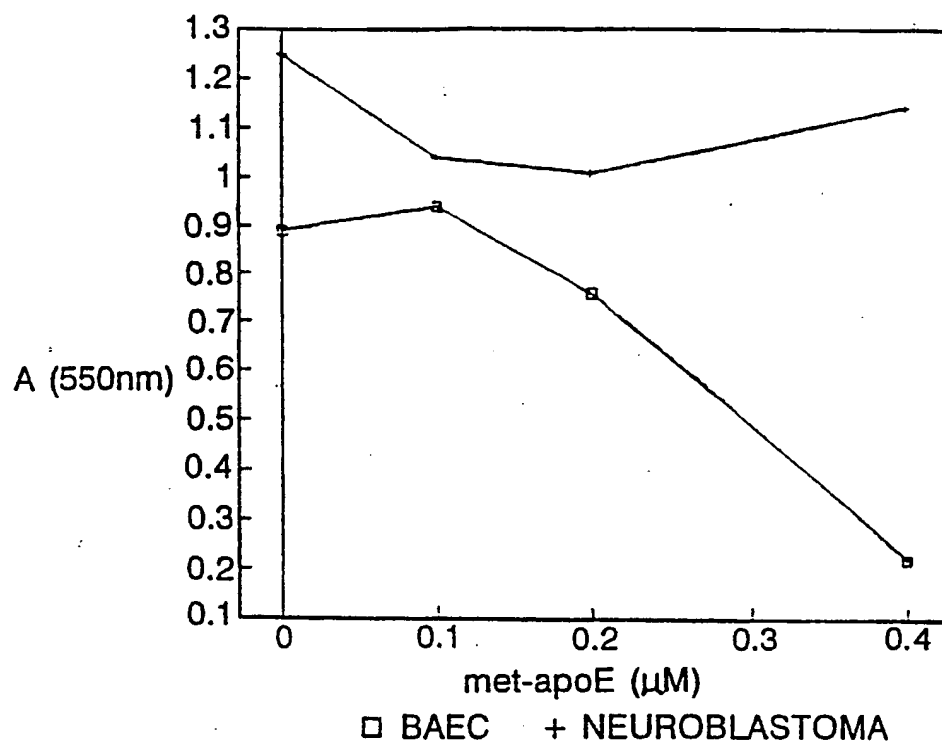
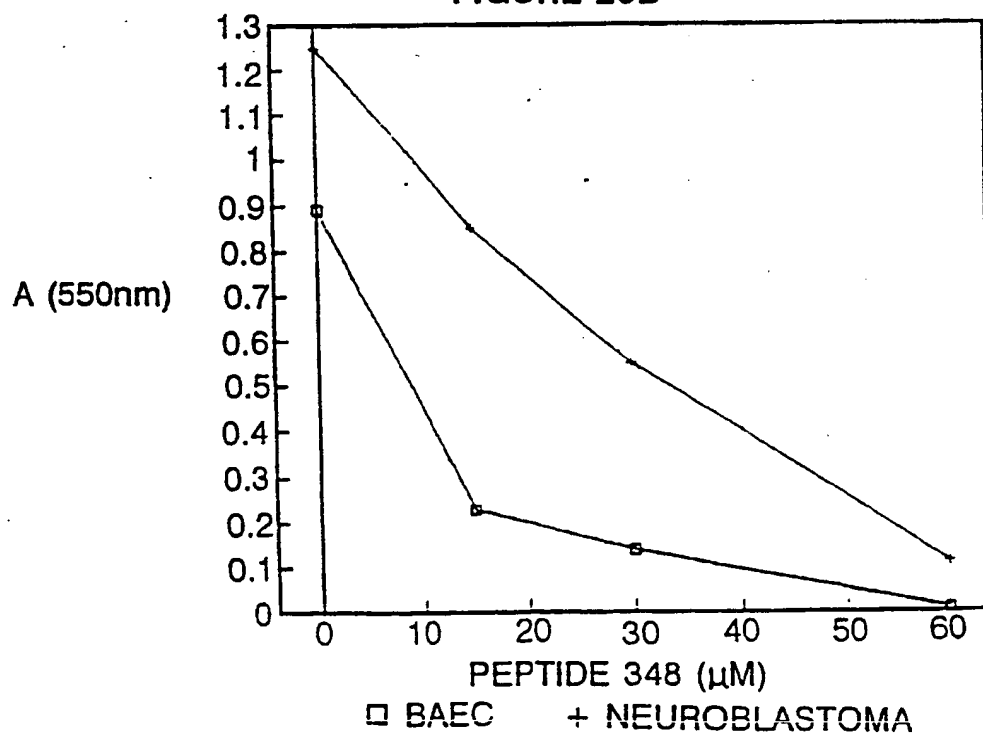
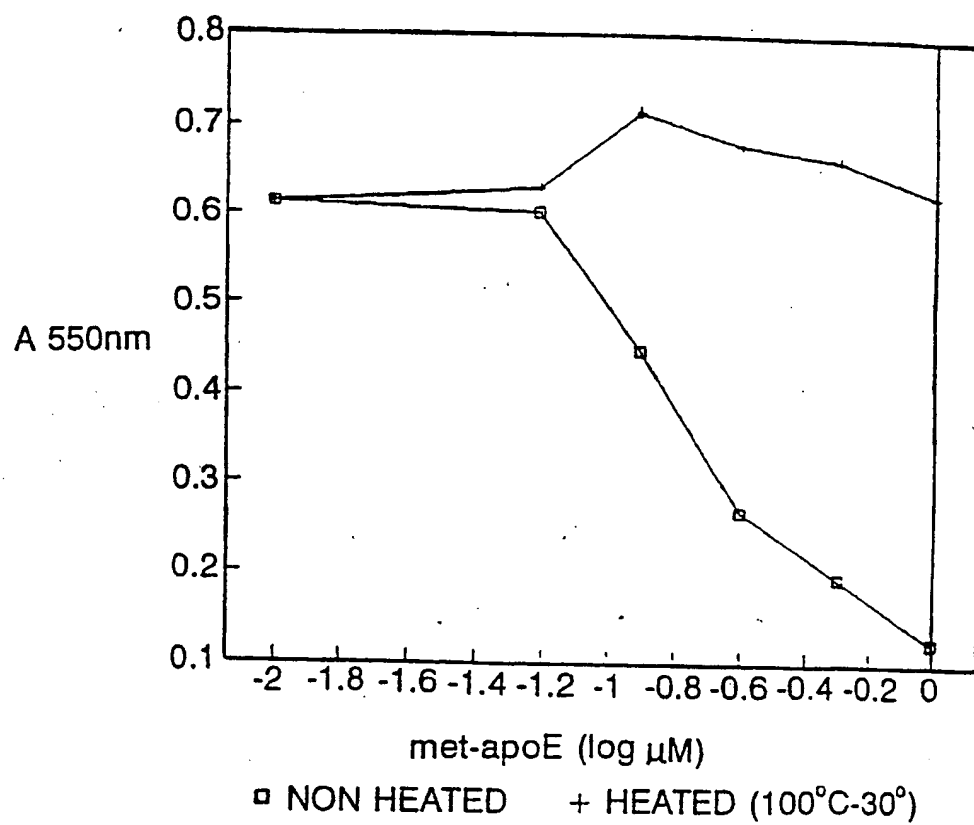
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FIGURE 20A

FIGURE 20B

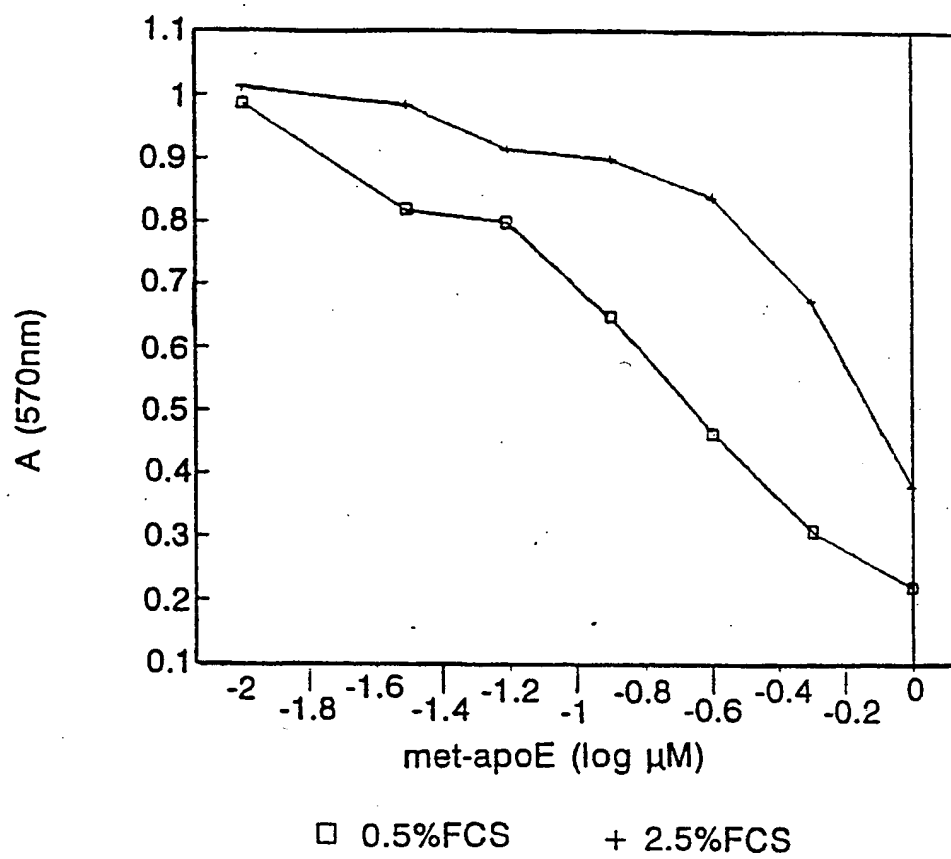


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FIGURE 21



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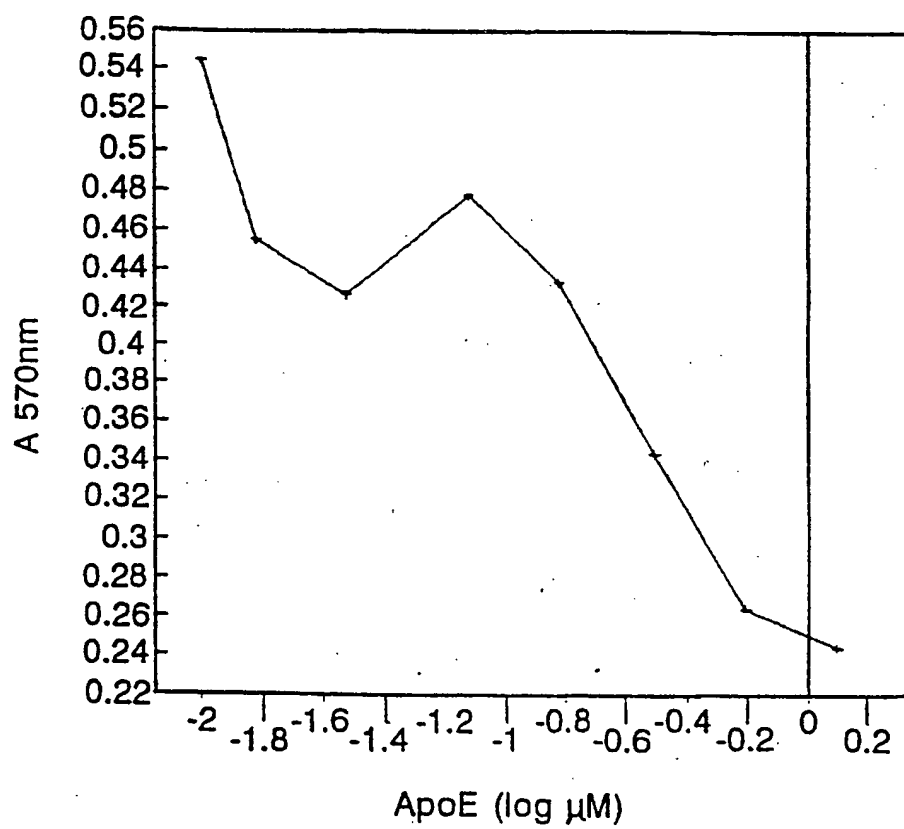
FIGURE 22



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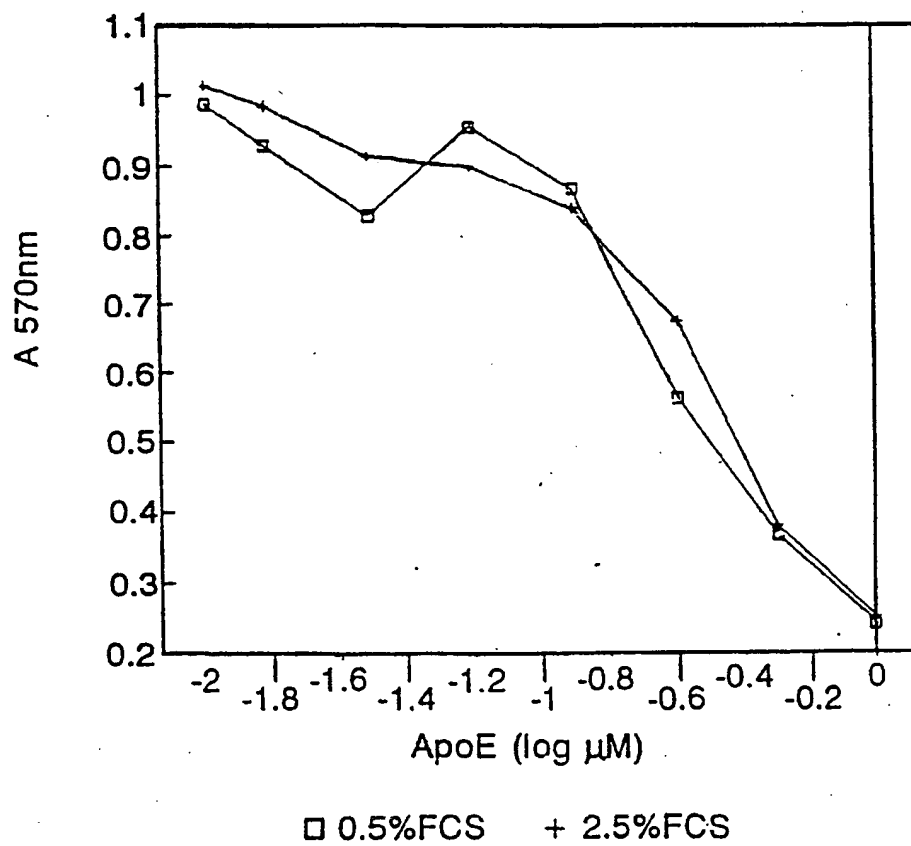
FIGURE 23



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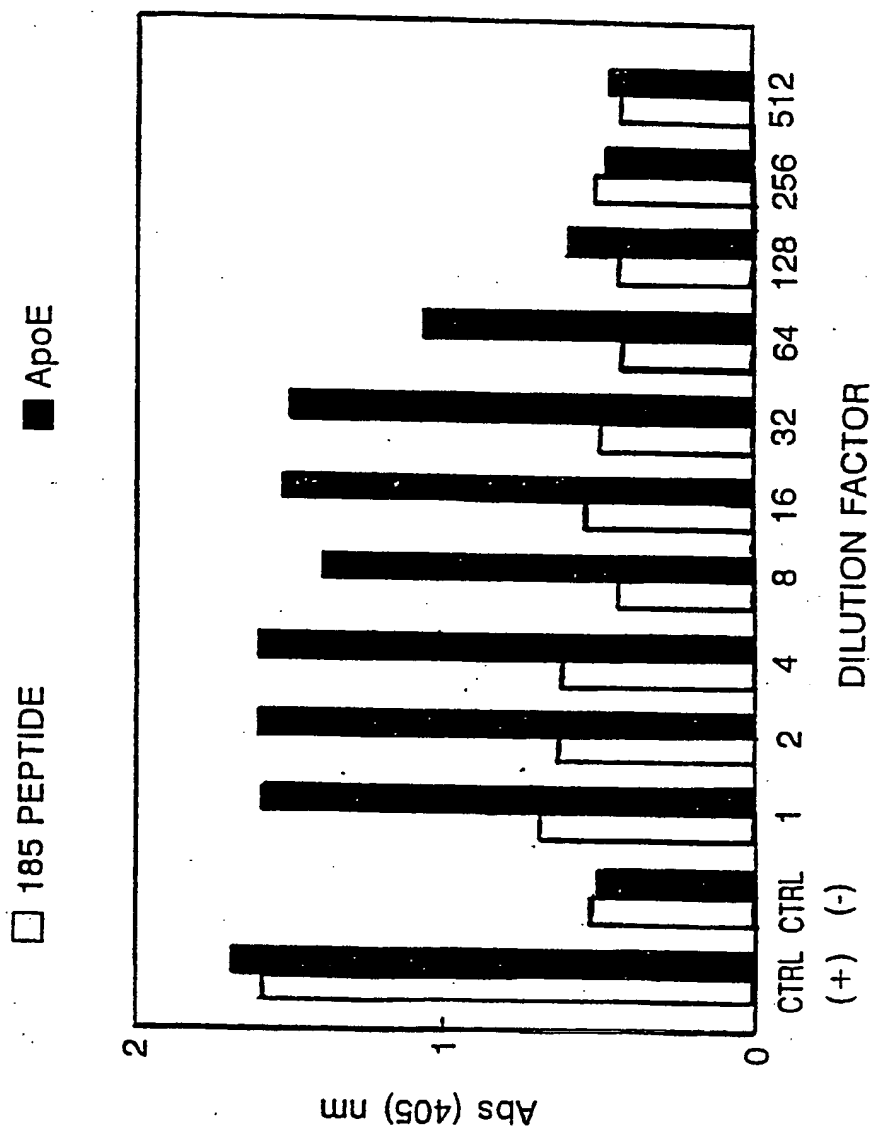
FIGURE 24



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FIGURE 25



## INTERNATIONAL SEARCH REPORT

International application No.

PCT/US93/07582

<b>A. CLASSIFICATION OF SUBJECT MATTER</b> IPC(5) : A61K 37/02, 37/22 US CL : 514/12, 530/380 According to International Patent Classification (IPC) or to both national classification and IPC																				
<b>B. FIELDS SEARCHED</b> Minimum documentation searched (classification system followed by classification symbols) U.S. : 514/12, 530/380  Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched  Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) APS, Dialog: Medline, Biosis Previews, WPI																				
<b>C. DOCUMENTS CONSIDERED TO BE RELEVANT</b>																				
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.																		
A	Science, Volume 240, issued 29 April 1988, R. W. Mahley, "Apolipoprotein E: Cholesterol Transport Protein with Expanding Role in Cell Biology", pages 622-630, entire document	1-28																		
A	Biochemical and Biophysical Research Communications, Volume 154, No. 2, issued 29 July 1988, A. D. Cardin et al, "Inhibition of Lymphocyte Proliferation by Synthetic Peptides Homologous to Human Plasma Apolipoproteins B and E", pages 741-745, entire document.	1-28																		
<input type="checkbox"/> Further documents are listed in the continuation of Box C. <input type="checkbox"/> See patent family annex.																				
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